A SURVEY OF MANAGEMENT TRADE-OFFS THROUGH THE SHIP ACQUISITION LIFE CYCLE

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THROUGH THE SHIP ACQUISITION LIFE CYCLE

by

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This study surveys the performance, cost, and schedule trade-off process during the ship acquisition cycle, from identification of the need to delivery of the ship. The dialogue between the ship user and the ship producer to develop the ship system requirements and translate the need into a ship which meets the user's requirements is discussed. The survey investigates the trade-off techniques used by many of the individuals within the ship project

offices of the Naval Ships Systems Command. As a result of investigating how these individuals attempt to optimize the variables of performance, cost, and schedule, some conculsions are drawn and recommendations made for future consideration in the ship acquisition process.

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Through the Ship Acquisition Life Cycle

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GLOSSARY OF TERMS

AAW	- Anti-Air Warfare
ABL	- Allocated Baseline
ASPR	- Armed Services Procurement Regulations
ASW	- Anti-Submarine Warfare
CCB	- Change Control Board
CER	- Cost Estimating Relationship
CFE	- Contractor Furnished Equipment
CIWS	- Close-in Weapon System
CNO	- Chief of Naval Operations
COGAS	- Combined Gas and Steam
CV	- Aircraft Carrier
DDG	- Guided Missile Destroyer
DE	- Destroyer Escort
FIT	- Fleet Introduction Team
FYDP	- Five Year Defense Plan
GFE	- Government Furnished Equipment
KW	- Kilowatt
LHA	- Amphibious Assault Ship
MDCS	- Maintenance Data Collection System
MIL STD	- Military Standard
NAVELEX	- Naval Electronics Systems Command
NAVMAT	- Naval Material Command
NAVORD	- Naval Ordnance Systems Command
NAVSEA	- Naval Sea Systems Command

NAVSEC - Naval Ship Engineering Center

NAVSHIPS - Naval Ship Systems Command

OPNAV - Office of the Chief of Naval Operations

PADS - Performance Analysis Data Sheets

PARM - Participating Acquisition Manager

PSA - Post Shipyard Availability

PTA - Proposed Technical Approach

SCB - Specifications Control Board

SCN - Ship Construction Navy Appropriation

SCS - Sea Control Ship

SES - Surface Effects Ship

SHAPM - Ship Acquisition Project Manager

SSN - Submarine, Nuclear Powered

SSBN - Fleet Ballistic Missile Submarine, Nuclear Powered

SUPSHIPS - Superintendent of Shipbuilding

TDP - Technical Development Plan

TLS - Top Level Specifications

TLR - Top Level Requirements

VDS - Variable Depth Sonar

VCG - Verticle Center of Gravity

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I. INTRODUCTION

The acquisition of ships for the Navy is a long, difficult, and complex process. Major weapon system procurement policies have undergone significant changes within the past few years. Former Deputy Secretary of Defense David Packard formulated many new policies which were promulgated by Department of Defense Directive 5000.1, "Acquisition of Major Defense Systems." Admiral E. R. Zumwalt, the former Chief of Naval Operations, restructured the missions and priorities for ship acquisitions. The developments in these two areas, naval missions and procurement policy, during 1969 and 1970 required reconsideration of recent ship procurement procedures to overcome the recognized shortcomings of past approaches, and respond to the new priorities of the revised missions and procurement policies. The procurement approach and procedures which have evolved are quite different from those of the 1960's, although they do attempt to imitate successful aspects of these past procurements and reflect lessons learned.

A. THESIS OBJECTIVES

The principal objective of our research into the ship acquisition process was to identify those features of programs which may have significance for future programs, especially in the area of cost, schedule and performance trade-off decision making. Early in the research effort it became

apparent that the bulk of the data on this subject would have to come from interviews with the personnel within the Navy who are involved in the ship acquisition process. It would be necessary to discuss the ship acquisition process with the personnel who are concerned with the process from the identification of a need for a new ship through the construction of that ship. Consequently, the authors made two visits to Washington, D. C. to discuss the problems inherent in many different ship acquisition programs and the approaches and techniques that have been used to attempt to solve the problem of making the optimum decision with respect to trade-offs.

A trade-off is a means of analyzing the interrelationships between various performance, cost and/or schedule variables in order to obtain a balance among these variables which maximizes cost-effectiveness. Thus, trade-offs are the means of optimizing ship design by the personnel involved in the ship acquisition process. Trade-offs are made continually throughout the acquisition process, and it is possible for a trade-off to be made within one, two or all three of the cost, performance and/or schedule variables.

The research and analysis of the ship acquisition process and trade-off decision making impacts required an investigation into the identification of military needs that spawn the ship requirement, the technical approaches used to satisfy the ship requirement, and the approaches used to design, develop and construct the ship. The implications of the new Department

of Defense and Navy procurement policies and requirements on future Navy shipbuilding programs are also discussed. While planning, directive and procurement documents and correspondence were used during the investigation, a great reliance was placed on data obtained by interview to complete the research and analysis reported in the succeeding chapters.

B. CHAPTER OUTLINES

Chapter Two describes the ship acquisition life cycle, how the ship programs are initiated, the periods and phases of a ship acquisition process and the requirements of each period and phase. The discussion points out the requirements for a continuing dialogue between the ship user, the Chief of Naval Operations, and the ship producer, the Navy Material Command through its Naval Ship Systems Command. The chapter concludes with a discussion of the magnitude of the trade-off problem and the features of this problem that must be considered when making the optimal trade-off choice.

Chapter Three discusses in greater depth the dialogue between the user and producer and the responsibilities of each in the determination and development of ship system requirements. The influences of the user are discussed, from need identification to identification of desired operational parameters required in the ship. The influences of the producer are presented by discussing how the conceptual design process is accomplished, essential ship system parameters are identified, how the Ship Acquisition Project

Manager can mold all of the information derived from various sources into a viable, produceable ship, and how the project manager can manage the necessary changes in his ship as the design and construction process progresses.

The discussion in Chapter Four centers on the trade-off techniques and considerations given to cost, schedule and performance. The influence of each of these dimensions of the trade-off problem is discussed, and some of the tools used by project managers and ship designers to resolve the trade-off problem are indicated. Performance and some of the operational parameters which affect performance are discussed, along with some of the tools and techniques which are available to analyze and measure performance. The effect of cost, the problems in estimating cost and examples of how cost and performance can be used to make trade-offs are shown. The influence of schedule and the importance of the ship acquisition time line are presented in the concluding portion of the chapter.

Chapter Five discusses the conclusions and recommendations of the authors with respect to: Conceptual Design and Advanced Development Studies, Design and Development Techniques, Construction Phase Impacts and the requirement for developing a procedure to document Lessons Learned in the Ship Acquisition process.

II. SHIP ACQUISITION CYCLE AND THE TRADE-OFF PROBLEM

A. SHIP ACQUISITION CYCLE

A ship, to be useful, must satisfy an operational need, for Naval ships, such an operational need usually results from a military threat. In addition, the ship must be able to continue to meet the need over a specified long period of time in order to justify the investment in time, money, and effort. Thus, one must consider the life cycle of a ship in a dynamic sense, the so-called "cradle-to-grave" viewpoint. The ship life cycle may be said to originate upon the recognition of its need and to terminate when the ship is retired as obsolete.

A ship's life cycle may be originated in one of two ways, as a result of a new threat or need resulting from a new scientific or technological breakthrough, or as an iteration of an existing ship which is no longer cost-effective and whose life cycle is nearing completion (the so-called "second generation"). The new generation ship, therefore, can be expected to satisfy an increased need or perhaps the original need in a more effective manner.

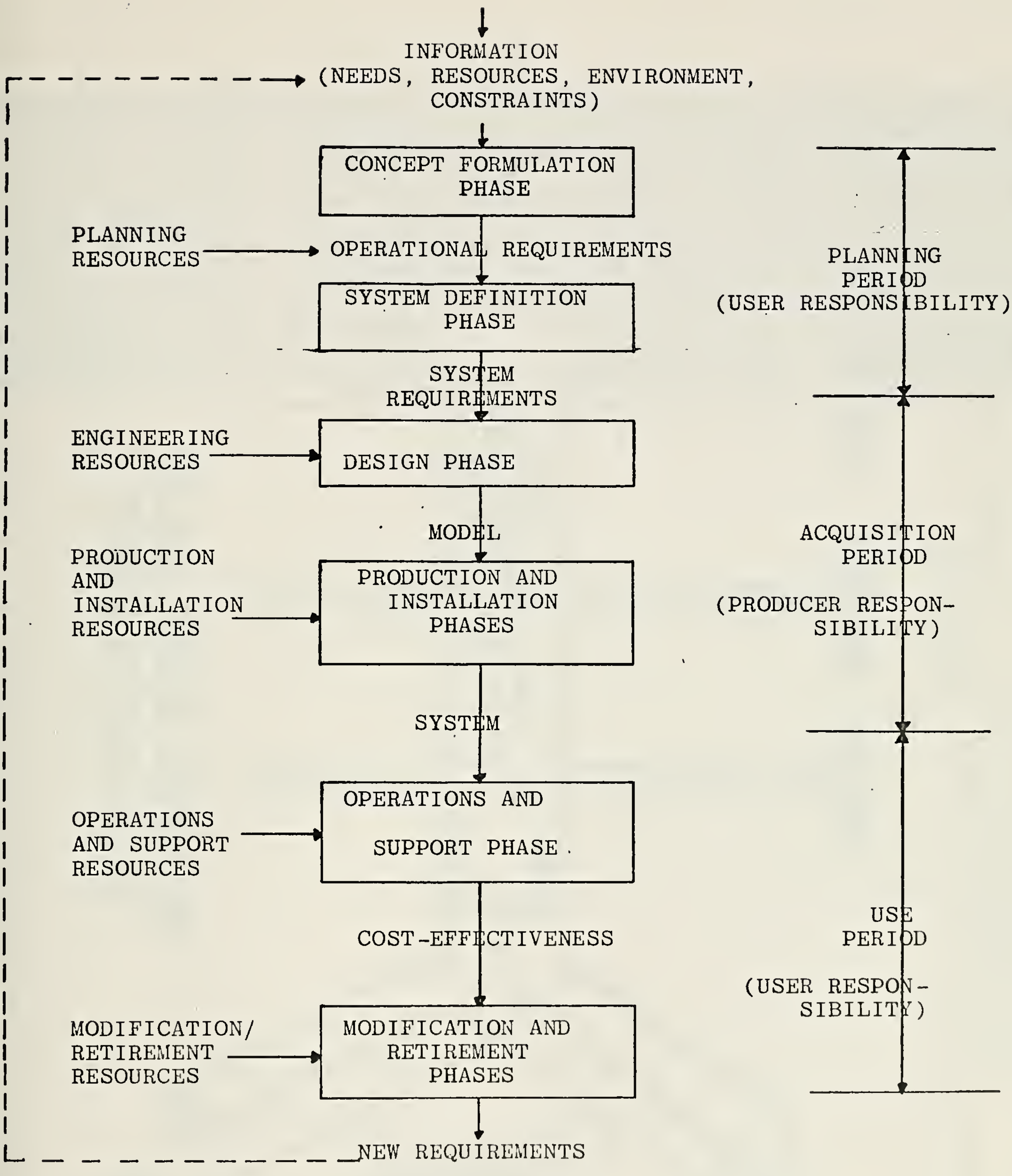
In the Navy, a ship's useful life is often considered to be 20 to 30 years. Sometimes the anticipated life of a ship is not effectively realized because provisions for system growth to meet requirements are not incorporated during original ship planning.

In the evolution of a ship's design, construction, and employment, a number of phases exist between the two end-points of the ship's life which, in turn, are subsets of three distinct periods - the Planning Period, the Acquisition Period, and the Use Period. Figure 2-1 indicates the various phases and periods, along with the inputs and outputs of each.(1)

B. USER-PRODUCER DIALOGUE

With some exceptions, ships that have been constructed for the Navy have resulted from an interaction between users and producers. In the Navy, the user is the Fleet and is represented at headquarters by the Office of the Chief of Naval Operations (OPNAV). The user is concerned with stating and developing the needs and concepts for the mission of the ship and for its operation and support. He provides the input requirements to the ship design.(2) With the assistance of supporting organizations, new requirements (usually threats) are analyzed and missions formulated. This leads to the specification of requirements constrained by the availability of resources, the environment and the technological state-of-the-art. See Figure 2-2.

The producer must generate the design or performance specifications so that the resultant Navy ship, when designed and constructed, meets the requirements of the Fleet. Within the Navy, the producer role is represented by the Naval Material Command (NAVMAT) and its Systems Commands. For ships, the producer is the Naval Ships Systems Command (NAVSHIPS).



SYSTEM LIFE CYCLE

Figure 2-1

Source: Modification from Ref. 2

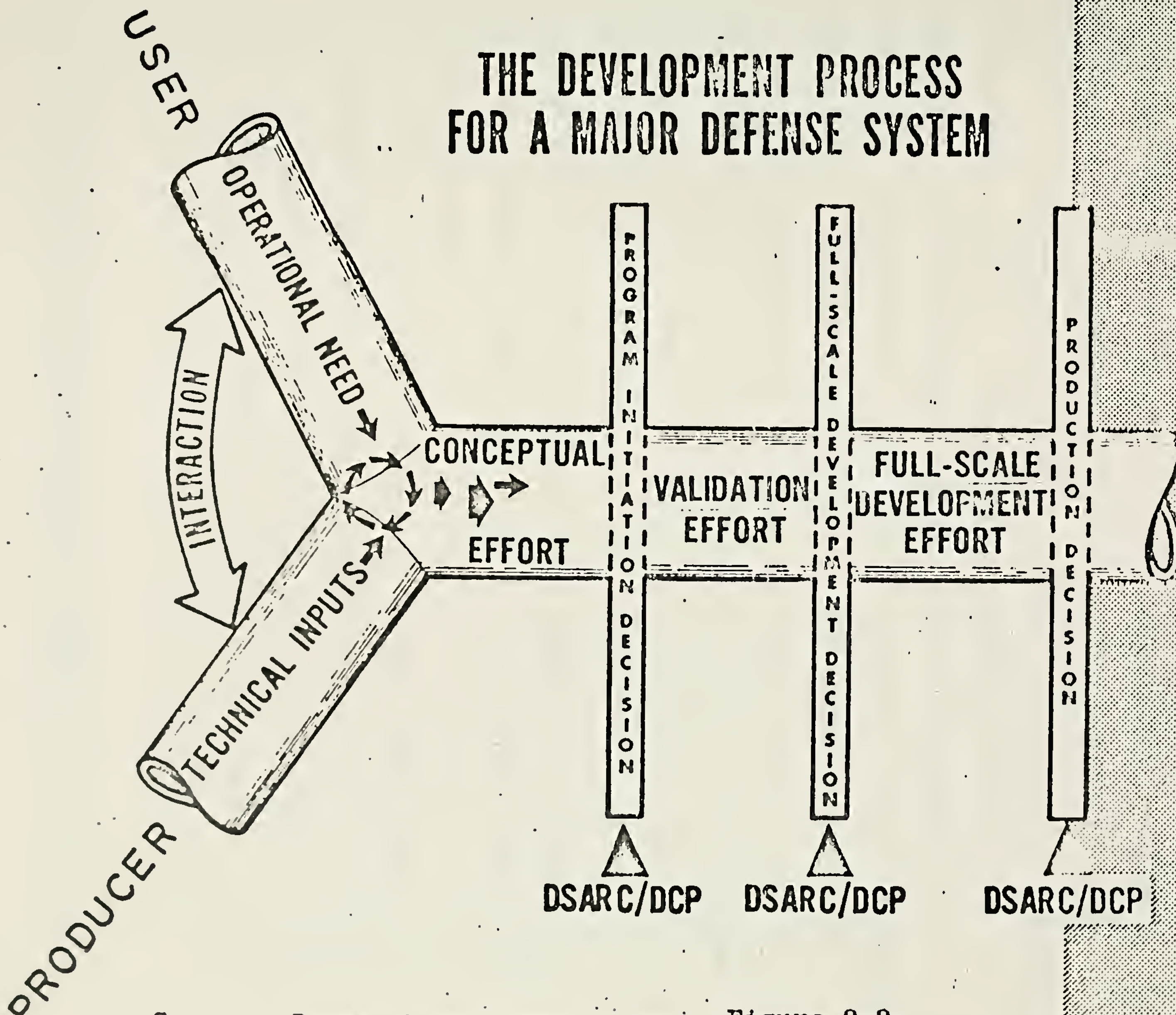


Figure 2-2

Source: Research and Development in the Department of Defense...a management overview. November 1971.

NAVSHIPS and its internal functional elements are assisted by Navy laboratories, other Navy organizations, and industry in translating ship requirements to conceptual design models that will meet the need and remain within the stipulated cost and performance characteristics.

The interaction or dialogue between user and producer is a complex iterative process. The dialogue must continue throughout the acquisition cycle if a cost-effective ship is to be designed and produced. Figure 2-3 depicts the formal and informal lines of communication between the user and producer. On the user side, under OPNAV, are supporting analytical organizations, the Program Sponsor, and the Program Coordinator. The Program Sponsor is the voice of the Fleet in the user organization and insures that resources are available for the program and remain available. The Program Coordinator is the user's direct liaison contact with the producer's Project Manager, and serves as the focal point between the two organizations. The Program Coordinator strives to maintain the visibility of the program within and outside the Navy.

On the producer side, under the Chief of Naval Material is NAVSHIPS and other Systems Commands which must be relied upon for support in the ship acquisition. For example, the Naval Ordnance Systems Command (NAVORD)* is responsible for providing the ship with its weapons systems and the Naval

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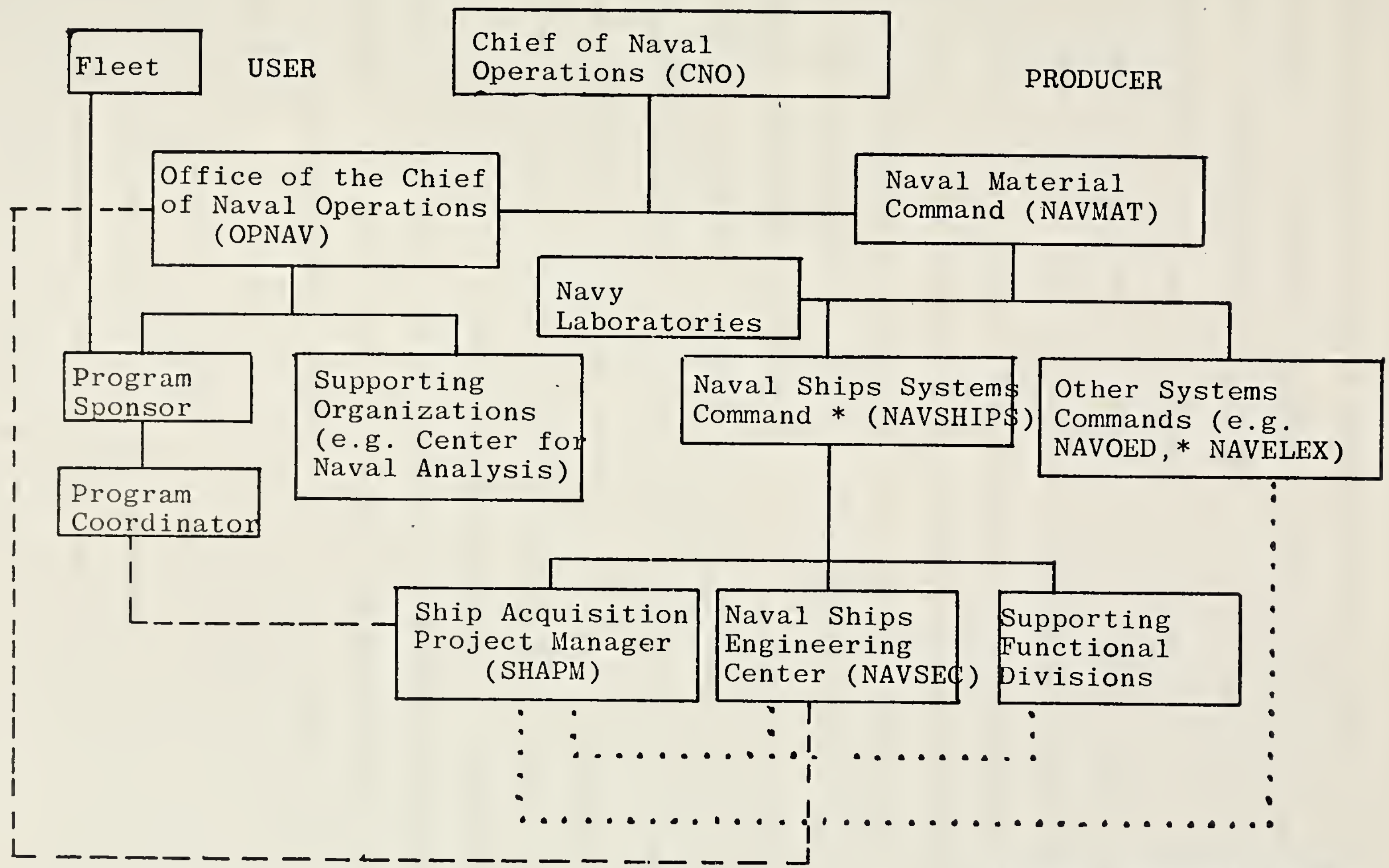
*As of 1 July 1974, NAVSHIPS and NAVORD were combined to form the Naval Sea Systems Command (NAVSEA).

USER-PRODUCER RELATIONSHIPS FOR SHIP ACQUISITION



* As of 1 July 1974 NAVSHIPS and NAVORD were combined to become the Naval Sea Systems Command (NAVSEA).

———— Formal Organizational Lines of Communication

- - - - - User-Producer Line of Communication

· · · · · Intra-Producer lines of Communication

Figure 2-3

Electronics Systems Command (NAVELEX) is responsible for providing the ship with its communications system. The Ship Acquisition Project Manager (SHAPM) is the key decision maker for the producer activities and the dialogue link to the user side. He has the prime responsibility for developing the technical requirements of the ship, and for ship design and construction. The Naval Ships Engineering Center (NAVSEC) is essentially the engineering department of NAVSHIPS and is involved in the acquisition process from concept design through modification during the use period. The other supporting functional divisions of NAVSHIPS assist the Project Manager by providing expertise in cost estimating, contracting, production, logistics, and other business management functions.

Interviews conducted by the authors with Project Managers and their staffs concerning the user-producer dialogue elicited the general opinion that there were major shortcomings in the way this process was actually being conducted. The consensus was that, by default, NAVMAT rather than OPNAV was determining the needs of the Fleet and that there was no formal documentation of the ship definition process. In order to improve the documentation of the user-producer dialogue with respect to ships, a series of documents called a Top Level Requirement (TLR), produced by the user, and a Top Level Specification (TLS), the response by the producer, was recently instituted. TLR/TLS is discussed in Section III A.

C. THE NATURE OF THE TRADE-OFF PROBLEM

The life cycle of any ship includes a continuing series of management and technical compromises called trade-offs. They commence during the early stages of the life cycle and continue through engineering development, production, deployment, maintenance, and modification until the ultimate decision to replace the ship with one of higher performance or improved cost-effectiveness is made. The principal differences in these trade-offs concern the level at which they are made as the acquisition process proceeds through the life cycle. In the early stages, trade-offs are made at the system level, while in the later stages of the cycle, trade-offs are made at the component equipment level. Of all major weapons systems, naval ships present the most complex problem in achieving meaningful trade-off decisions. A naval ship is a multi-functional system whose active life usually exceeds the life span of contributing shipborne systems by a factor of two or three. Thus, trade-offs and optimizations of design cannot readily be done intuitively by the designers. Instead, all technical and cost factors as well as development time must be identified and defined, and the trade-off justified and documented.

Trade-offs are used to obtain a practical balance between cost, schedule and performance of systems. In this context, cost includes all costs of acquisition and ownership; performance includes all factors influencing effectiveness in operational use, such as reliability and maintainability;

and the system includes all hardware and other required items such as facilities, personnel, data, training, and equipment.

The weighting factor or relative value assigned to the worth of various system elements is subject to wide variation. Depending on the particular program, technical risk, financial or political considerations, or personnel ceilings may take precedence at any given time. However, the fundamental considerations are that the approved choice must be financially acceptable, be technically feasible, have the required performance capability, be militarily useful, and be available in a timely manner.

The fundamental considerations which affect the trade-off problem are as follows:(3)

1. Risk

Risk may be defined as the measure of uncertainty involved in meeting requirements or technical characteristics, budgeted funding levels, or schedules. Whenever trade-off studies are conducted, the degree of risk associated with each alternative should be identified and assessed, and that risk must be controlled.

Technical risks may appear when attempts are made to introduce features which have not been successfully demonstrated previously. Other causes of technical risk include inadequate definition of operational performance objectives (uncertainties in requirements) and insufficient test demonstration of equipment. Even though these and other risks

are minimized during development, there is always a chance that, in the operational environment, performance requirements will not be met, there will be reliability/maintainability problems, and/or service approval could be denied.

2. Operational and Performance Factors

Operational and performance factors constitute prime areas of consideration when making trade-offs. For example, operational factors to be considered include the threat or operational need which is the basis for determining the mission and functional requirements, requirements for each system in terms of the relationship to other systems, and anticipated deployment considerations, such as the number of installations and operational locations. With respect to ship performance, trade-offs must be made keeping in mind the minimum acceptable values of such operational parameters as speed, range, endurance, and other essential aspects of ship system performance. Consideration must also be given to the functional capabilities of shipborne systems, subsystems, or equipments that must be compared and evaluated against the mission requirements comprising the performance envelope.

3. Physical, Functional, and Environmental Parameters and Limits

Elements such as size, weight, facilities, and service requirements require careful thought when trade-offs are being considered. These include:

- Weights - weight limits and moment effect.

• Dimensions - size and shape, crew space, operator station layout, and maintenance accessibility.

• Command and control - communication, computer base, tactical data, navigation, and radar systems.

• Vulnerability factors of competing subsystems - chemical, biological, radiological, electromagnetic radiation, fire, and shock considerations.

4. Reliability

Considerations of reliability are of major concern in system selection. Reliability for evaluation and comparison between competing systems should be expressed in quantative terms. To permit ready evaluation of the effect of trade-offs at the subsystem or equipment level, system reliability should be broken down into the reliability of the subsystem and equipment components.

5. Maintainability

Assessment of maintainability for trade-off purposes would include evaluation of such factors as:

• Level of maintenance required (ship's force, tender, depot level).

• Ease of component or unit replacement.

• Commonality and interchangeability of units.

• Preventive maintenance requirements.

• Spare parts logistics.

6. Personnel Factors

Personnel factors include as assessment of each competing system in the light of manning, skill level,

training and human engineering requirements or problems. This estimate also provides an insight into relative system or equipment complexity.

7. Facilities

Requirements for construction, purchase or development of new facilities or modification of existing facilities to support an alternative under consideration as a trade-off possibility should be evaluated. These include advance base, training, repair, and logistic facilities.

8. Compatibility

In the development of a ship system, the compatibility of systems, subsystems, and equipment is of paramount importance to ensure that no interfacing parameter is inadvertently overlooked. Each trade-off analysis must include a separate assessment of all factors which affect compatibility.

9. Standardization

The requirement for standardization acts as a constraint on system design because it will influence the trade-off decisions made during the design effort. Design engineers must identify and exploit opportunities to use interchangeable items for similar functions in order to achieve optimum commonality within particular systems to reduce logistics support.

10. Safety

Safety must also be considered during trade-off studies to assure the protection of individuals from injury or death and to prevent damage to or loss of equipment or property. Alternatives under consideration must satisfy safety regulations and requirements such as fail-safe and redundancy, and rescue and survival procedures.

The above considerations serve to emphasize the complexity of the trade-off problem and expose its impact on the ship acquisition process.

III. DEVELOPMENT OF SHIP SYSTEM REQUIREMENTS

In this chapter specific areas which are the responsibility of the user and the producer are discussed. The process of requirement determination by the user and the methods used by the producer to respond to these requirements are described.

A. TOP LEVEL REQUIREMENTS/TOP LEVEL SPECIFICATIONS

Beginning in the 1960's, greater emphasis on life cycle costing coupled with increasing complexities of ship requirements and weapons systems have emphasized the need for improvement of the systematic, timely flow of supporting decision-making documentation with which to control the ship definition process. This has been accompanied by declining fleet assets and escalating costs, tighter management control, increased review by higher authority, and sharply increased test and evaluation requirements related to operational performance.

Historically, the Office of the Chief of Naval Operations (OPNAV) initiated the user-producer dialogue by means of "single sheet characteristics" to state requirements. The "single sheet characteristics," contained information relating to such requirements as speed, length, draft, ordnance and electronic system capability, endurance and habitability. The producer responded by means of a proposed technical approach (PTA) and subsequently when an approach

was approved by OPNAV a technical development plan (TDP) was written. The Top Level Requirements/Top Level Specifications (TLR/TLS) concept, implemented in January 1974, replaces the "single sheet characteristics," PTA, and TDP, and will be used in the formulation of all new ship designs except Fleet Ballistic Missile Submarines. It will include, where practical, those current ship acquisitions which are in the early phases of the ship acquisition life cycle.

When needs and mission requirements for a particular type of ship have been defined, the program sponsor will initiate the formal user-producer dialogue which leads to the establishment of ship parameters and constraints, program initiation and finally the design and construction of the ship. Initial contact between OPNAV and NAVMAT will be between the existing functional organizations. This is where the user-producer dialogue begins.[4]

A user-producer working group composed of OPNAV and NAVMAT personnel, plus other organizations as may be required, will be formed to develop initial requirements. These initial requirements will be used by NAVMAT to determine the feasibility and cost of a ship which will potentially meet the stated mission requirements. Although the initial documents can be expected to contain undefined and incomplete areas at this early stage of the ship acquisition life cycle, they will permit the initiation of the design effort and facilitate the rational, documented development of information on which to base trade-off decisions.

The alternatives developed by NAVMAT are presented to OPNAV for review and decision. These decisions will then lead to a further refinement of the requirements and further design iterations. Effectiveness versus cost will be a major trade-off criterion. At this early stage of development, schedule is usually of lesser importance. A cost goal will be established by CNO as early as possible for the delivered cost of follow ships* in constant dollars of a particular fiscal year. Unlike aircraft, which lend themselves to assembly line production, ships are constructed like buildings, and the construction time for one ship is measured in years. Because of this long time the development and construction process results are not fully known until the first ship has completed construction, test and evaluation. Consequently, the cost of construction difficulties and design changes are assigned to the first ship.

If it should develop at any stage of the design process that the established requirements cannot be met within constraint limits, the problem together with its limiting constraints, alternative courses of action, and recommendations for proposed changes are brought to the CNO for decision and further direction. When the final characteristic decisions are made, the requirements will be formalized and issued as the TLR. [4]

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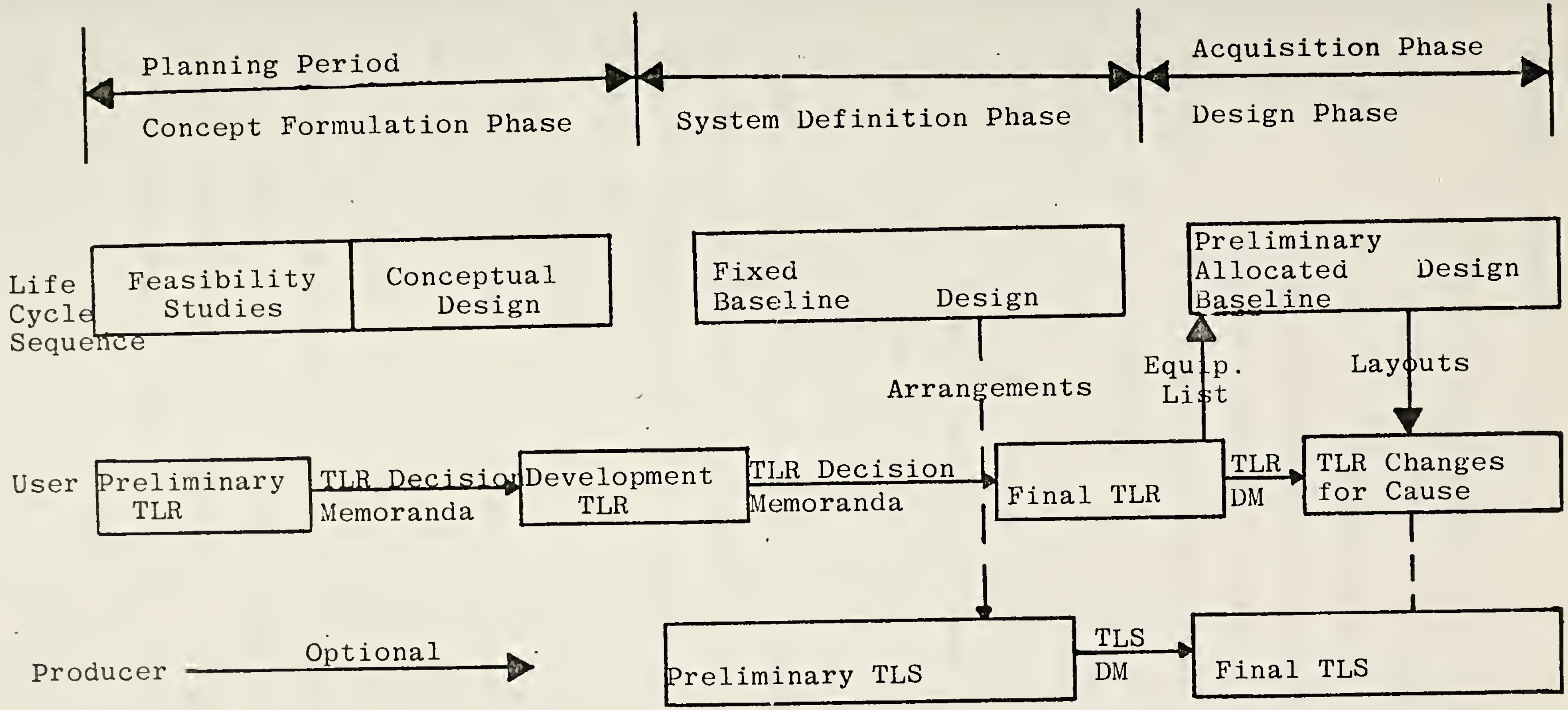
* Follow ships are those ships which succeed the first ship through the construction process.

As an important part of the user-producer dialogue established early in the conceptual phase, the development of the Top Level Specifications by NAVMAT will proceed in parallel with the development and refinement of the requirements. These specifications will indicate those portions of the requirements which are being satisfied, and they will be kept current with the requirements. Subsequent to the issue of the TLR, the TLS will be finalized, approved and issued by NAVMAT.(4) This document will provide a bridge between the TLR and the ship procurement specifications. Figure 3-1 shows in block diagram format the relationship of TLR and TLS preparation with the overall design effort. The definition of specifications in parallel with the definition of requirements vastly improves the iteration process which in the past had the specifications defined after the requirements had been finalized. The past process was much less efficient with respect to consumption of time and other resources.

The supporting documentation, which records ship requirements and program constraints, together with the trade-off decisions and changes developed during the dialogue between OPNAV and NAVMAT are an important part of the iterative process. This documentation becomes the TLR, and it will be maintained current throughout the life of the ship. The documented response to the TLR becomes the TLS, detailing the design configuration of the ship.



TOP LEVEL REQUIREMENTS/TOP LEVEL SPECIFICATIONS (TLR/TLS) RELATIONSHIP WITH OVERALL DESIGN EFFORT

Source: Modification from Ref. 4

Figure 3-1

B. USER CONSIDERATIONS

1. Threat, Mission, Age of the Fleet Analysis

As indicated in Section II A, the following are the primary reasons that determine the need for new ships:

- To meet the new threats and operational needs
- To replace obsolete units

Threat and mission analysis determines what new or continuing threats to the United States and/or allied countries must be countered, and the most cost-effective means to meet these threats. For example, the Destroyer Escort (DE) was developed primarily to counter the enemy submarine threat against open ocean convoys. The Aircraft Carrier (CV) was developed in order to provide a mobile attack air strike capability against enemy targets at sea or on land. Threat and mission analysis, as applied to ships, should result in a conceptual idea of what the ship will look like and what it will require to perform as desired.

Obsolescence of current fleet units is predicted and contained in the "Average Age of the Fleet" portion of the entended planning annex to the Five Year Defense Plan (FYDP). This annex shows when budget dollars will be required to replace current ships by projecting ahead some eight to ten years. When the time to begin acquisition of replacement units is approached, an analysis is performed to determine if the threat still exists and the mission still requires a Navy asset to satisfy it. At the same time, a determination can be made to ensure that a ship is the cost-effective

alternative.[5] For example, when a large number of minesweepers were decommissioned near the end of the Vietnam War, the mission of minehunting was taken over by helicopters with their dipping sonars and towed sweep equipment.

2. High-Low Mix Concept

During his first 60 days as Chief of Naval Operations (CNO), Admiral Zumwalt conducted a detailed study to assess the Navy's strategic position for presentation to the Secretaries of Defense and Navy. "Project Sixty," as it was called, examined trends in international politics and economies, world trade, sources of critical raw materials and defense fiscal expectations. It also identified critical deficiencies which affected the balance of naval power between the United States and Soviet Union. Resulting from "Project Sixty" has been a massive modernization of Navy ships, aircraft and weapons. This modernization has taken three forms, one of which is the balanced high-low mix concept. As applied to ships, this concept calls for a few multi-purpose high-cost ships together with larger numbers of single-purpose low-cost ships.[6] The single-purpose ship uses all of its designed capability to maximize its probability of accomplishing one mission. Multi-purpose ships sacrifice single-purpose efficiency to be able to perform multi-purpose missions in the most effective manner.[7]

"Project Sixty" showed that sea control, the maintenance of access to and use of worldwide sea lanes by United States and allied commercial and military shipping,

should be elevated to a major role and brought into better balance with the strategic deterrence and strike missions which had been predominant since the end of the Korean Conflict.

Between 1955 and 1970, the Navy's shipbuilding programs had reflected the emphasis on strike and strategic deterrence missions. The major portion of the Navy's shipbuilding budget had gone toward the construction of complex, high-cost nuclear submarines, conventional and nuclear-powered aircraft carriers, and conventional and nuclear-powered multi-purpose carrier escorts. Although some single-purpose ships, such as Destroyer Escorts, had been constructed, the bulk of the low-threat environment, non-carrier mission, such as convoy escort and coastal patrol, was being accomplished by World War II vintage ships. With the increased importance of the sea control mission, there was clearly a need for new ships to replace the older vessels in low-threat environment duty.

Examination of this need indicated that large numbers of these new ships would be required to provide adequate coverage. Ideally, the ships' design should reflect the projected nature of their roles in the 1980's and beyond rather than simply to duplicate, in more modern versions, the obsolete capabilities of the World War II ships that they would replace.

This definition of the need is only part of the problem faced by the Chief of Naval Operations. The

experience of the 1960's, the growing technical sophistication of military weapon systems, and the inflationary trends of the economy made it obvious that the cost of the required number of fully capable technologically up-to-date, multi-purpose ships would be prohibitive. To pursue this course in an era of increasing unit costs and shrinking military hardware acquisition budgets would require unacceptable curtailment of other on-going programs.

In order to obtain the numbers of ships needed, the Navy would build large numbers of ships of lesser capability, not lesser quality, along with smaller numbers of full capability ships. The high-low combination would provide a fleet with the optimal overall mix of capabilities required to meet the projected threat. The first program to implement this philosophy was the Patrol Frigate (PF) as the destroyer escort for amphibious or merchant convoys, this ship class being near the low end of the mix. An example of a multi-purpose ship is the Guided Missile Destroyer (DDG). This ship is capable of performing carrier escort, anti-submarine warfare (ASW), and anti-air warfare (AAW) missions.

The implementation of the high-low mix concept resulted in a different approach to mission analysis. Cost has become the driving factor in the development of low-mix, single-purpose ships. Single-purpose (low mix) studies are being accomplished in the submarine area. For instance, here the use of a low-cost, possibly non-nuclear, submarine for

barrier patrol missions is being investigated.[8] The high-low mix concept has set the stage for the ship requirements of the 1980's.

3. Platform Parameters and Constraints

Under the present system, with the Top Level Requirements/Top Level Specifications concept not yet fully implemented, OPNAV is still delivering to the technical commands a set of parameter requirements (single sheet characteristics). These requirements are those items which OPNAV feels are necessary for the ship to have in order to fulfill the mission the ship is desired to accomplish. The technical commands utilize those requirements to determine whether they can conceptually design a ship with these desired features and have it remain within predetermined cost boundaries. As a general rule, the threshold values of the following parameters are given to the technical commands for their further work: ship speed, draft, length, and endurance. These items are discussed in Section IV A. In addition, OPNAV may specify propulsion type, number of propellers, habitability requirements, ordnance, and electronic capability. In the past few years, OPNAV has also specified a cost constraint.

Other less well defined operational parameters of the ship, such as turning radius, acceleration, sea keeping, and diving depth (for submarines) are resolved on a give and take arrangement between the user and the producer. These initial give and take decisions are some of the earliest trade-off decisions made in the acquisition process. When the area of

concern is about items such as stability or buoyancy, the approach presented by the technical command is usually approved, since the engineers are the experts in these areas.

C. PRODUCER CONSIDERATIONS

1. Conceptual Design Studies

Normally, the first input by the technical commands to the acquisition cycle of ships is made during the time period when conceptual design studies are being accomplished. Feasibility studies assist the ship user in determining the ship system requirements to perform its assigned mission. These studies develop trade-offs primarily between performance and cost; since schedule is somewhat less important a factor at this early phase. In addition to the absolute capability of the ship and its cost, the marginal capabilities of the ship systems and their costs are important to the trade-off decision. Therefore, a large number of design concepts must be studied. Design approximations are investigated since absolute accuracy would be impractical at this point.

2. Synthesis Models

Synthesis models are used during the conceptual design phase to explore a large number of design iterations in order to converge on an approximately correct solution to the user's problem.(9) These models can be used to develop a series of consistent ship designs, since they are able to methodically iterate the design each time the input parameters are changed. The following methodology is used by NAVSEC

in the construction of the synthesis models it uses to develop the initial conceptual designs. All NAVSEC models contain the following general features:

a. Considerations Which Predetermine the Ship's Geometry

In order to estimate the volume, weight, and power requirements for a ship, it is necessary to know the ship's geometric envelope. This envelope includes the underwater hull, the hull from the design waterline to the main deck, and the superstructure. It is also necessary to explore major subsystem locations, e.g. propulsion machinery aft, or amidships, because this will have an impact on stability and center of gravity. General arrangement considerations must also be included, since adequate space must be provided to accept what is to be installed inside the ship. Damage stability or watertight integrity must be investigated to make the design capable of sustaining battle damage and still remain afloat.

b. Design Strategy

In the models currently used, either of two design strategies may be invoked. Each strategy starts by assuming a certain number of specific ship parameter values, e.g. length, draft, depth, displacement, center of gravity, and architectural coefficients. Synthesis begins in the same manner for each strategy by making calculations in a given sequence. Once calculations are complete, they are compared to acceptable criteria. If the calculations differ from the

acceptable criteria, then the selected design strategy is invoked. In one strategy, a completely new combination of specific values of the ship parameters is selected and evaluated when the design is determined to be invalid. The other design strategy performs design iterations by changing some of the previously determined design parameters to converge on a design which will meet acceptable criteria.

c. Cost Estimating Relationships

Cost estimating relationships (CER's) are derived either explicitly or implicitly. An explicit CER is based on cost data from older ships whose performance and physical characteristics are similar to the ship being investigated. Situations occur in which cost estimates are desired or required, but the information necessary for explicit CERs is unavailable. At such times highly subjective (ball park) estimates are frequently used and can be justified as more useful than no estimate at all. Such estimates are implicit CERs, inasmuch as the estimator may be subconsciously extrapolating from prior experience through the use of an unformulated or vaguely conceived extrapolation to the new item from older items. The CERs thus obtained can be used to measure the total impact of the selection of certain parameters, e.g. the weight of main propulsion machinery as a function of shaft horsepower for twin and single screw ships and the weight of main propulsion machinery as a function of machinery foundation requirements. Through the interaction of these CERs the requirement for the machinery

foundation is able to be estimated from the shaft horsepower.

d. Estimating the Physical Characteristics

One of the key elements in developing a synthesis model is obtaining or attempting to fix at some level, or within a narrow range, the physical characteristics of the ship. Estimations must be made of the requirements for items such as total kilowatts at 60 Hz, total kilowatts at 400 Hz, gallons per minute of cooling water at a required temperature, tons per hour of low pressure cooled air for air conditioning, and gallons per day of distilled water. Not only must these characteristics be fixed, but the correlations and interdependencies among them must be considered. The correlation of the various items that together make up the total requirements is often accomplished by use of multiple regression analysis. Two dangers arise however, the first of which is that the resulting equation is used in the synthesis model outside its range of applicability. The second danger, is that the correlation is incorrectly accepted as an independent variable when it is in fact dependent.(9)

e. A Limited Number of Alternative Subsystems

This requirement is necessary because a synthesis model is limited to including only those ship subsystems for which it has estimating relationships. For example, a combined diesel or gas turbine main propulsion machinery subroutine may be available but a combined steam and gas turbine machinery subroutine may not be.

In addition to giving a specific design solution, a synthesis model is useful in performing sensitivity analysis by means of "what if" questions. One can postulate an improvement at the subsystem level and explore its impact on requirements at the ship system level.

Figure 3-2 lists some synthesis models, study projects using them and the number of design iterations accomplished at NAVSEC over a six year period (1967-1973). The DD07 model shown in Figure 3-2 has been used in all of the recent studies of destroyer type ships.

3. Military Effectiveness Model

Another type of model used by NAVSHIPS to investigate trade-off alternatives is the Military Effectiveness Model, developed for the Amphibious Assault Ship (LHA) project. This model uses a mathematical expression to determine military effectiveness. In order to measure effectiveness, the desired performance of the equipment or system under consideration must be defined as precisely as possible. Selection of parameters to be optimized was based on the following criteria:

a. The parameter is significant in performance of of the basic mission.

b. The parameter has a quantitative value established by operational requirements.

c. The value of the parameter can be predicted during preliminary design.

STUDY	NO. OF ALTERNATIVE DESIGNS	SYNTHESIS MODEL
MAJOR FLEET ESCORT	50	DD07
DX/DXG CONCEPT FORMULATION	800	DD07
DX CONCEPT FORMULATION	200	DD07
DXG CONCEPT FORMULATION	50	DD07
DXGN CONCEPT FORMULATION	200	DD07
MAJOR FLEET FLAG	130	DD07
OLD LFS - CONCEPT FORMULATION	1,000	DD05
NEW LFS - CONCEPT FORMULATION	500	DD07
MCS - CONCEPT FORMULATION	700	MCSH
AGS - CONCEPT FORMULATION	200	AGS
LHA - CONCEPT FORMULATION	750	LHA
FLEETREP (CNA)	100	UNREP
PCE	140	DD07
AO FEAS.	60	UNREP
PATROL ESCORT (PF)	150	DD07
SEA CONTROL SHIP (SCS)	350	DD07 MOD
TRIDENT	492	ULMS
DG AEGIS	200*	DD07
T&E SHIP	21*	DD07
SWATH	450*	LWP

*As of March 1973

SHIP SYNTHESIS MODEL USAGE IN NAVSEC BEGINNING IN ABOUT 1967

Source: NAVSEC

Figure 3-2

d. The value of the parameter can be varied by the design engineers during preliminary design.

e. The value of the parameter can be determined during contract design.

In the LHA project, military effectiveness was determined by considering the number of troop accommodations, the troop vehicle offload time, preloaded areas, the cargo delivery rate, the number of helicopter landing spots, endurance, speed, survivability, reliability, availability, draft and overhaul cycle to name a few.(10) Each of these factors was built into a mathematical model, weighted as appropriate, and then the model was solved using a number of different iterations varying the value that was under investigation.

4. Development of Essential System Parameters

A study of the elements that drive the ship design is fundamental to an examination of their impact during the development of naval ships. The parameters or parameter ranges dictated by OPNAV serve as a starting point for the process of identification of essential system parameters.

Ships were once weight limited; that is, the size of the hull was determined by the amount of buoyancy needed to support the total of the component weights. Today, because of the specification requirements issued by OPNAV, the space requirements for armament, electronics, and people, rather than their weights, dictate ship size. Thus, ships are now volume limited. The ship design engineer exercises more

control over hull volume than any other parameter he deals with. The present requirements for items such as habitability and crew support as well as the importance attached to them have a large impact on the volume problem. As a result, ship manning has become an essential design parameter.

The machinery space in a ship is a "large object" space, i.e., space is determined by specific dimensions of specific large items of equipment. The volume of the machinery space is a function of beam, which is generally not determined by the ship width required to hold the individual pieces of machinery as they are arranged side by side, but is governed by stability requirements and hence a function of the position of the center of gravity. Consequently, stability, propulsion plant machinery, electrical generation capability and air conditioning capability are essential design parameters.

5. Change Management

Typically a project office is established after a ship has been sized and the conceptual design has already been accomplished. At this time the project manager finds that his world of trade-offs has been partially constrained. The user-producer dialogue has been established by this time and the initial cost and performance trade-offs have been accomplished by the conceptual design process with the Program Sponsor working directly with NAVSEC. The emphasis of the project manager at this stage of the process is to study the proposed conceptual design and mold it into specifications which can be used to request bids from industry

for the detailed design and construction of the ship. Additional studies will be conducted to insure that all aspects of the proposed ship characteristics have been investigated. The project manager will also be evaluating the impacts of the ship design on a proposed schedule. Thus, schedule now becomes a full-fledged partner in the trade-off analysis on an equal basis with performance and cost. The project manager, through his dialogue with OPNAV, will make refinements to the ship design, make recommendations for changes to the requirements which resulted in the conceptual design, and modify other design aspects as appropriate.

When the construction contract is awarded, the project is in the acquisition period (Figure 2-1). During the later parts of this period the trade-off world of the project manager shifts from one of influencing the design process to one of balancing performance, cost and schedule aspects of change proposals, particularily since ship construction must start before detail design is completed. In the process of resolving the questions posed by the change proposals and evaluating their impact on performance, cost, and schedule, project managers are assisted by a Change Control Board (CCB), NAVSHIPS Specifications Control Board (SCB), the Superintendent of Shipbuilding (SUPSHIPS) at the contractor facility, and other supporting organizations.

The Change Control Board (CCB), when properly constituted and organized, can be one of the most useful in-house aids that is available to the project manager to

assist him in making trade-off decisions on proposed changes. The function of the CCB is to investigate, analyze and report to the project manager what the change involves, the alternatives, if any available, the impact on performance, cost and schedule, and the recommendation of the CCB as to the best course of action. The usefulness of the CCB is aided by including in the board's deliberations all offices which have an interest in the proposed change.

The Specifications Control Board (SCB) reviews and evaluates the total impact of proposed changes to specifications. In the course of the construction of his ship, the project manager may need to modify some particular ship specifications, in which case he would refer to the SCB for its analysis of the effect of the change to accepted specifications. The project manager may also use the SCB to review for completeness such items as design data sheets, development work statements or purchase descriptions issued for the procurement of feasibility demonstration hardware. Thus, the SCB is a group outside of his immediate organization that the project manager can turn to for assistance to aid his decision-making process.

The Superintendent of Shipbuilding (SUPSHIPS) is the eyes and ears of the project manager at the contractor site where the ship is being built. SUPSHIPS will receive the change proposals from the contractor and make an initial evaluation of the possible impact of the change from his

viewpoint prior to forwarding them to the project office. The recommendations of the SUPSHIPS of the impact on performance, cost and schedule of a proposed change is one of the inputs the project manager will utilize when making his trade-off decisions.

IV. TRADE-OFF TECHNIQUES

Many techniques are available to the project manager to help him maintain a balanced program, by means of cost, schedule, and performance trade-offs. One of the keys to designing and constructing a cost-effective ship is to be able to determine the effects and interactions of cost, performance, and schedule as design requirements. Some of the analysis techniques used in each area are discussed in this chapter.

A. PERFORMANCE AS A DESIGN REQUIREMENT

Many trade-off options are available to OPNAV as it specifies the required platform performance parameters. These trade-offs are often made prior to the initiation of a user-producer dialogue. Initial studies by the OPNAV analytical supporting organizations and the Naval Ship Engineering Center (NAVSEC) allows the first round of trade-offs to be made. As an example, NAVSEC conducted a study that evaluated the combined gas turbine and steam turbine propulsion plant as opposed to more conventional propulsion plants such as steam. This resulted from an interest in possible prime mover candidates for the guided missile destroyer which is to carry the Aegis missile system. The study compared the 850 psi steam system, a 30,000 horsepower gas turbine system, and a combined gas turbine and steam turbine system. Items

such as weight of machinery and fuel, reliability, availability, time required to get underway, acceleration and deceleration, alternate operating modes and risk to the ship development were all assessed. The study results provided OPNAV several trade-off options in selection of the desired propulsion plant. Interactions of ship platform performance parameters must be investigated fully to illuminate all of the trade-off options possible so that OPNAV can make a definitive judgment about what parameters it desires to hold constant. In the past, several parameters such as speed, endurance, and length have been fixed, possibly without total knowledge of their impact, and as a result many trade-off options were lost to the ship designer.

The impact of performance as a design requirement can be shown by the following examples:

1. Speed.

Ship speed and/or steaming profile, the speeds required by a ship to fulfill its mission, are specified by OPNAV to the designers because of the probable end use of the ship. If the ship is to be used as a carrier escort then it must be capable of carrier speeds. If the ship is a convoy escort then it must be as fast as the convoy plus an additional speed capability that will allow it to patrol around and ahead of the convoy. A replenishment ship must have sufficient speed to keep up with its task group and to safely conduct the replenishment operation. It must also be able to go to some restock point and return to the task group

as quickly as possible. The speed required of the ship will normally dictate how many shafts are required as well as influencing such items as engine horsepower and overall ship dimensions. Continuing analysis of speed can size and power a ship design, however many of the other factors discussed below will also impact speed, size, and power and will require trade-offs to select the most cost-effective approach.

2. Draft

Draft is also dependent on the proposed mission of the ship as well as the overall size of the ship. Draft is critical to the consideration of ship stability, sea keeping capability, and buoyancy, as well as speed. If a ship will always operate on the open ocean, then its draft is only restricted by the necessity of going into port. The super tankers, for instance, are not draft limited, since no port is capable of accepting them. If a ship is designed for coastal interdiction or protection, then its draft is critical because it must be able to operate in very shallow waters. Although the mission drives the draft requirement, it interrelates to other critical ship parameters such as speed and length.

3. Length

The length of a ship is a critical factor considered along with draft and width (or beam) of a ship to determine the platform stability. Length restrictions or ranges are specified to determine how much useful area or volume will be available in a ship to accommodate all of the systems that

the ship is required to carry. The length of a ship and its beam are used to calculate a design parameter known as the length-to-beam ratio. This ratio shows whether the relationship between length and beam for a particular ship type will satisfy minimum acceptable standards developed by naval architects. Tables of length-to-beam ratios versus other ship design parameters are used for further analysis of trade-offs. The platform or box shape of the ship, determined by its length, is one of the key parameters which is used to cost out a particular type of ship. Once shape has been determined, cost estimating relationships based on space and weight can be applied.

4. Endurance

The endurance required of a ship is normally determined by the mission the ship is to fulfill, and the time it is expected to be underway. If a ship is expected to operate with a task group, it can reasonably be expected that replenishment will be available. However, if a ship is expected to operate independently for long periods of time, it must have the endurance designed into it which will allow this type of operation. Endurance considerations affect the selection of engine or propulsion type, space required for fuel, provisions, and spare parts, and ordnance loading. Probable ship steaming profile has the greatest impact on the desired endurance. Experience in the past few years has been to design ships with longer endurances to minimize diversion from combat and because the fleet is more susceptible to

attack by an emeny during replenishment operations, and with declining fleet assets more missions are accomplished by lesser numbers of ships in more isolated locations.

As indicated in the four examples above, platform performance parameters are a critical feature in the ship design process and trade-offs must be fully investigated. Chapter III indicated how models can be used to measure the impact of these parameters on ship design. There are other techniques available to the project manager which he may use to measure or quantify performance in the design process. Some of these techniques are discussed in the next section.

B. PERFORMANCE TRADE-OFF ANALYSIS TECHNIQUES

The following techniques are used by the project manager and those who assist him in the ship design process. A brief discussion of each technique is presented. Specific details of each technique are available from the references listed in the Bibliography.

1. Performance Analysis

NAVSEC uses a technique of performance analysis known as PADS, which requires the existence of a design solution and certain information characterizing this solution to an existing problem. The procedure used in the performance analysis and documented in the data sheets can be defined as:

> ".......a way of demonstrating by analysis whether or not a given design solution meets a given set of requirements."[11]

The purpose of performance analysis is three-fold:

a. Assessment of Design Adequacy

Design validation or proof that the performance level supplied by the proposed design solution is equal to or exceeds the required/specified performance.

b. Trade-off Impact Assessment

Visibility as to what impact certain adjustments of the proposed design solution would have on performance (these trade-offs are very likely necessary to settle incompatabilities between performance requirements and a cost constraint).

c. Assessment of Optimality

Some indication as to what "price" has been paid for meeting the performance; this may mean indication to what degree the design solution exceeds the necessary performance or where in other areas sacrifices and/or expenditures have to be made in order to provide the existing design solution.

In certain cases a clear distinction between these three items may be very difficult; for example, a certain degree of optimality or "efficiency" may already be contained directly or indirectly in the required performance. In other cases, it may not be easy to define a criterion for quality or optimality. In still other cases, any trade-off impact assessment is meaningless because the performance requirement is mandatory or the item has been specifically called out as a must have requirement.

A study of performance analysis for stability and reserve buoyancy conducted by Hydronautics, Incorporated for NAVSEC shows the types of items considered by this technique.[11] In the case of reserve buoyancy analysis, it consisted of the determination of limiting drafts resulting from floodable length studies, and flooding water levels. The basis for determination of the extent of flooding is the length of damage to the shell of the ship at any point along the ship's length resulting from weapon attack or collision. The ship designer uses standard floodable-length curves to assist in establishing transverse bulkhead spacing. In addition for a given ship arrangement and a set of limiting drafts, it is possible to determine the final trim line after flooding of any group of adjacent compartments.

2. <u>Maintenance Engineering Analysis</u>

Maintenance engineering analysis is a tool that can be used along with life cycle cost analysis to help determine the reliability and maintainability requirements of the system under consideration and the maintenance resources needed to support the system. An analysis conducted for the SSN-688 Project Office on the three-inch launcher system was concerned with:[12]

• Data collection and analysis to obtain the performance history of similar equipment.

• Development and dissenination of reliability, maintainability, safety, and human engineering design requirements.

• Failure modes and effects analysis to identify critical components.

• Corrective maintenance analysis to identify corrective maintenance requirements, support, facilities, and so forth.

• Preventive maintenance analysis to establish a balanced scheduled maintenance program.

Collection and analysis of available performance history of similar components was conducted to facilitate estimating failure rates for components of the three-inch launcher system and to identify potential reliability and maintainability problem areas. The principal source of data was the Navy's Maintenance Data Collection System (MDCS). MDCS data on signal ejector system component malfunctions, as reported by numerous SSN and SSBN Class Submarines, were reviewed. Additional performance data was obtained from discussions with operating forces afloat during shipboard visits to nuclear submarines for the purpose of obtaining information concerning reliability, maintenance, and operational problems related to the signal ejector system. Specific areas discussed were accessibility and maintenance problems and system components experiencing repetitive failures. A third source of performance data was the equipment manufacturers.

During the detail design of the three-inch launcher system, reliability, maintainability, safety, and human engineering design criteria were developed and provided to

the system designers in the form of design criteria guidelines/checklists, reliability and maintainability problem reports, and safety hazard reports.

The likelihood and consequences of significant system failure modes were identified and investigated by means of a Failure Modes and Effects Analysis. The SSN-688 Class specifications, three-inch launcher system diagrams, detailed system drawings, and manufacturers' equipment drawings were utilized in conducting this phase of the analysis. This identified the failure modes which are likely to be encountered, their criticality, and their resultant effect on the system and ship.

A Corrective Maintenance Analysis was conducted and utilized the failure causes for each failure mode contained in the above failure analysis to establish the maintenance requirements necessary to effect repair. This analysis provided estimates of the time required to perform the total maintenance requirement for each component, the associated skill level needed, and identified the lowest repair activity level capable of performing the maintenance action in question.

The Preventive Maintenance Analysis was conducted to ensure that a balanced preventive maintenance program was established for the three-inch launcher system that will meet the needs of the equipment with a minimum of ship's resources expended. The analysis identified preventive

maintenance requirements along with the maintenance level. skill level, and time required for accomplishment.

In addition, in-depth studies were conducted to define the design configuration that offered the best compromise among all design alternatives. Design trade-offs and special studies were conducted as dictated by the results of the data research effort and all of the previous analysis studies. Constant system design monitoring was then instituted to insure that reliability and maintainability would not be degraded by design changes.

3. Technical Performance Measurement

Since it is desirable to provide guidance to assure that trade-offs are properly made, especially in the performance area, to quantify the likelihood of meeting or exceeding performance requirements and to assure that changes in the likelihood of meeting these requirements can be tracked, a quantification and tracking process has been devised called Technical Performance Measurement (TPM).[3]

MIL-STD-499 defines Technical Performance Measurement as: "TPM is the continuing demonstration and prediction of the degree of actual or anticipated achievement of selected technical goals or objectives of a system or part thereof, together with the causal analysis of the variance between achievement and objective. The purpose of TPM is to permit appropriate managers to take timely action on indicated problems."

The steps in measuring and tracking technical performance are:

a. Performance Variables

Determine the performance variables essential for technical success and establish performance functions or equations which relate performance variables to design variables. Typical ship performance variables are speed, range, endurance, and typical design variables are length, displacement, and installed shaft-horsepower. A typical ship performance equation would be:

$$\text{For speed} \quad \text{--} \quad V = K_o \times \left(\frac{\overline{PC}}{\overline{DC}}\right)^{1/3} \times \frac{P^{1/3}}{LW^{1/6}}$$

where, $\overline{PC}$ is a propulsive coefficient

$\overline{DC}$ is a draft coefficient

P is installed shaft-horsepower

LW is length in feet times displacement in long tons (2240 lb/ton)

K_o is a constant

b. Probability Distributions

Develop subjective probability distributions for the design variables, by making inquiries of experienced personnel. This interview technique systematically draws from past experiences the information necessary to reconstruct a range of expected design values and the associated probabilities. This probability distribution could be

checked for sensitivity to change or probability changes to measure the effect of the design variables. For example:

Design Variable	Range	Probability
Specific fuel consumption in lb/installed SHP/hour	.50 - .55	.3
	.55 - .60	.5
	.60 - .65	.2

c. Techniques

Using appropriate techniques, e.g., simulation, to determine the likelihood of meeting technical objectives or of obtaining desired performance. For example:

PROBABILITY DISTRIBUTIONS FOR SYSTEM PERFORMANCE CHARACTERISTICS IN A HYPOTHETICAL SHIP DEVELOPMENT PROJECT

V (knots)	16	17	18	19	20
p(V)	.15	.2	.45	.1	.1
Range (miles)	4000	5000	6000	7000	8000
p(Range)	.1	.2	.4	.25	.05
Endurance (hours)	3800	4000	4300	4400	4500
p(Endurance)	.25	.35	.2	.1	.1

d. Performance Tracking

Track changes in the likelihood of meeting performance objectives. This tracking can be by means of tables or graphs, which show probabilities for a ship attaining a given speed after construction for different periods of time, or to track the development of some system against a time line to determine if schedule will be attained along with the attainment of the desired performance.

Technical performance measurement parameters should be selected for one or more of the following reasons: mission/task critical; performance critical; state-of-the-art critical. These are often selected for contractural incentive parameters. All parameters must be measureable. A mission/ task critical parameter, for example, may be ship speed or range or endurance, or it may be associated with a subsystem such as a radar.

C. COST AS A DESIGN PARAMETER

The Department of Defense has stated in Directive 5000.1 that:

> "Cost parameters shall be established which consider the cost of acquisition and ownership; discrete cost elements (e.g., unit production cost, operating and support cost) shall be translated into 'design to' requirements. System development shall be continuously evaluated against these requirements with the same rigor as that applied to technical requirements. Practical trade-offs shall be made between system capability, cost and schedule. Traceability of estimates and costing factors, including those for economic escalation, shall be maintained."[13]

Unit costs of weapon systems have risen to such an extent and funds available to the Department of Defense have become so limited that a considerable disparity between requirements and resources has developed. This was recognized

when Directive 5000.1 was promulgated. Unit production costs are a part of life cycle costs and must be considered as a primary design parameter, but not at the expense of increased ownership costs or through the sacrifice of performance essential for mission accomplishment.

As specified in the JOINT DESIGN-TO-COST GUIDE[14] the "Design-to-Cost" concept utilizes unit production cost as a criterion for project manager decisions and as a design parameter for engineers. To be really meaningful as a design parameter, unit production costs must be realistically established and represent an appropriate value for the item. "The best possible design to perform the mission must be obtained for the established unit cost goal," according to the guide. The guide also states, "The design must be iterated to obtain the best cost, schedule, and performance trade-offs within the established thresholds. If redesign cannot achieve the unit production cost goal, there must be trade-offs made to reach the maximum performance possible, at the cost goal, and still assure that a viable weapon system design is obtained." The intent of the design-to-cost concept is to design to a unit production cost, i.e. make unit production cost a design parameter. Design-to-Cost is based on the application of learning curves to the production process. Since ships are constructed and not produced in large quantities, the total ship system does not lend itself readily to the application of this concept as true learning curve efficiencies are never achieved. The

concept of design-to-cost can be utilized for the production of ship subsystems, however it must be remembered that cost should be a design variable and not just a design constraint.

Since the "Design-to-Cost" concept has evolved, several new Navy ship developments, starting with the Patrol Frigate (PF) program, are being designed to a cost ceiling. In the PF project, total ship cost was specified as a design constraint which would cause performance and schedule to be traded off within the cost constraint. Only when cost is a design variable, can a balance be reached between cost, schedule and performance.

The cost ceiling design procedure differs from the past practice of designing primarily to operational requirements. Operational requirements are still the central issue in ship design, but budget limitations have dictated an approach other than designing the most capable ship. Currently, and for the foreseeable future, changes to designed operational capabilities will be balanced with an eye to their marginal costs. During design, a significant effort is required to discover and control changes which would cause the cost of the ship to grow.

As a ship proceeds through its design phases, the cost estimates become more accurate because more and more is known about the ship and its installed systems. The greater the accuracy of the cost estimate, the easier it is to evaluate the marginal cost impact of various systems against the cost ceiling. This provides the ship designer with a

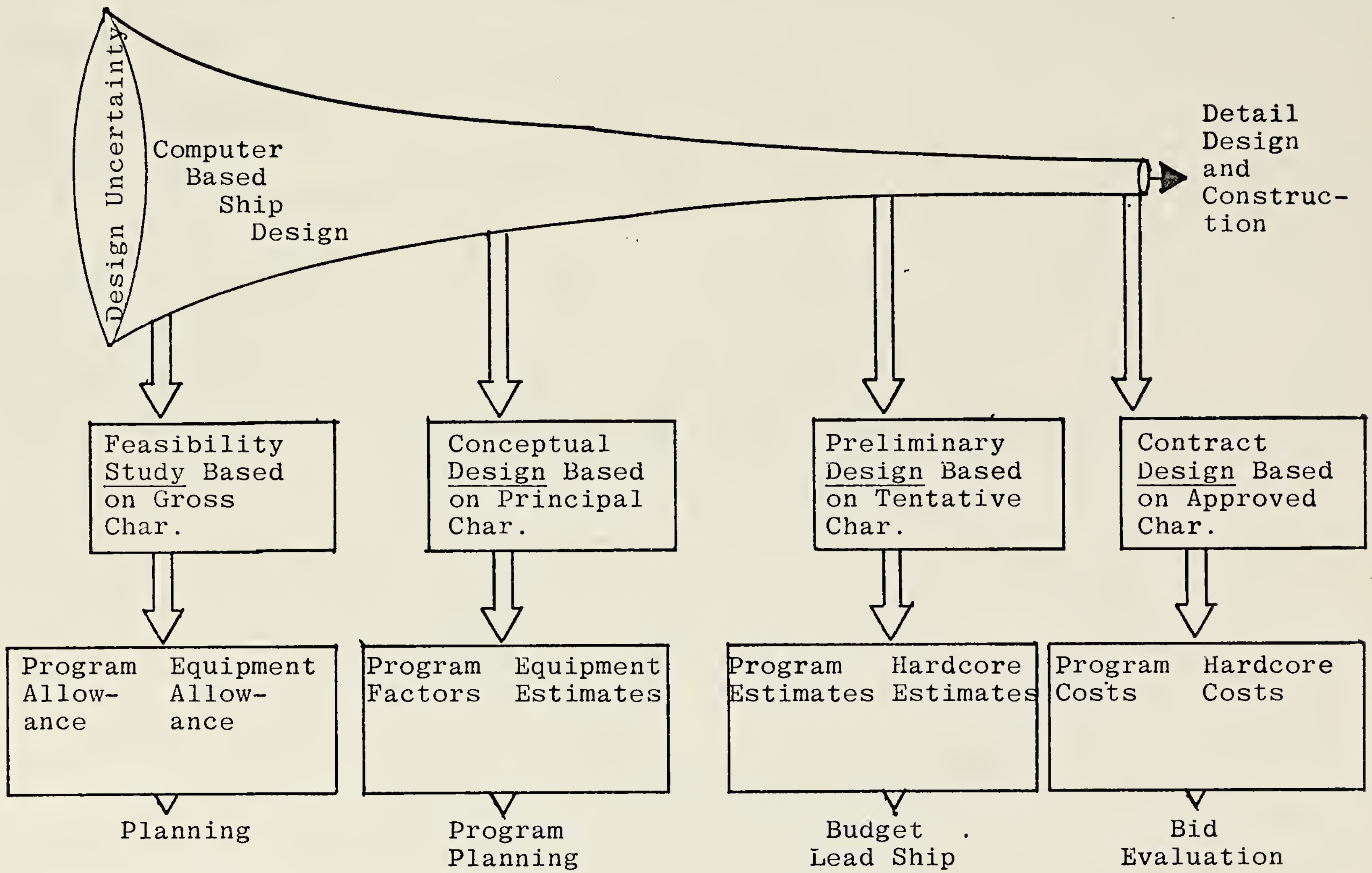
means of trading off alternative systems or subsystems in the design process. The major elements of ship acquisition cost which are used as the basis for ship design cost iterations are shown in Appendix A.

Ship characteristics and design practices utilized are limited by the trade-offs required to keep the ship design within its cost ceiling. Initially, the major system trade-offs will have a smaller impact on the total cost. During feasibility studies, the ship design is controlled by gross characteristics to accomplish the stated goals, and one is only concerned with total cost being within some designated cost ballpark. During conceptual design, using more specific guidance, with respect to certain parameters of the ship, cost can be determined more closely by considering the individual incremental costs of changing some of the design characteristics. As the ship design is further defined, the specific cost impact of different subsystems and equipments can be examined to measure their effect on the total ship cost. Figure 4-1 shows the evolution of a ship cost baseline. The ship design spiral depicted in Figure 4-2 shows the process wherein the ship is progressively defined in increasing detail. The tighter the spiral the more design definition and more accurate the cost estimation.

1. <u>Design Cost Estimating and Its Problems</u>

Within NAVSHIPS, cost estimates are provided by personnel who rely on specific information which describe the characteristics and configuration of a ship. Two methods

EVOLUTION OF SHIP COST BASELINE



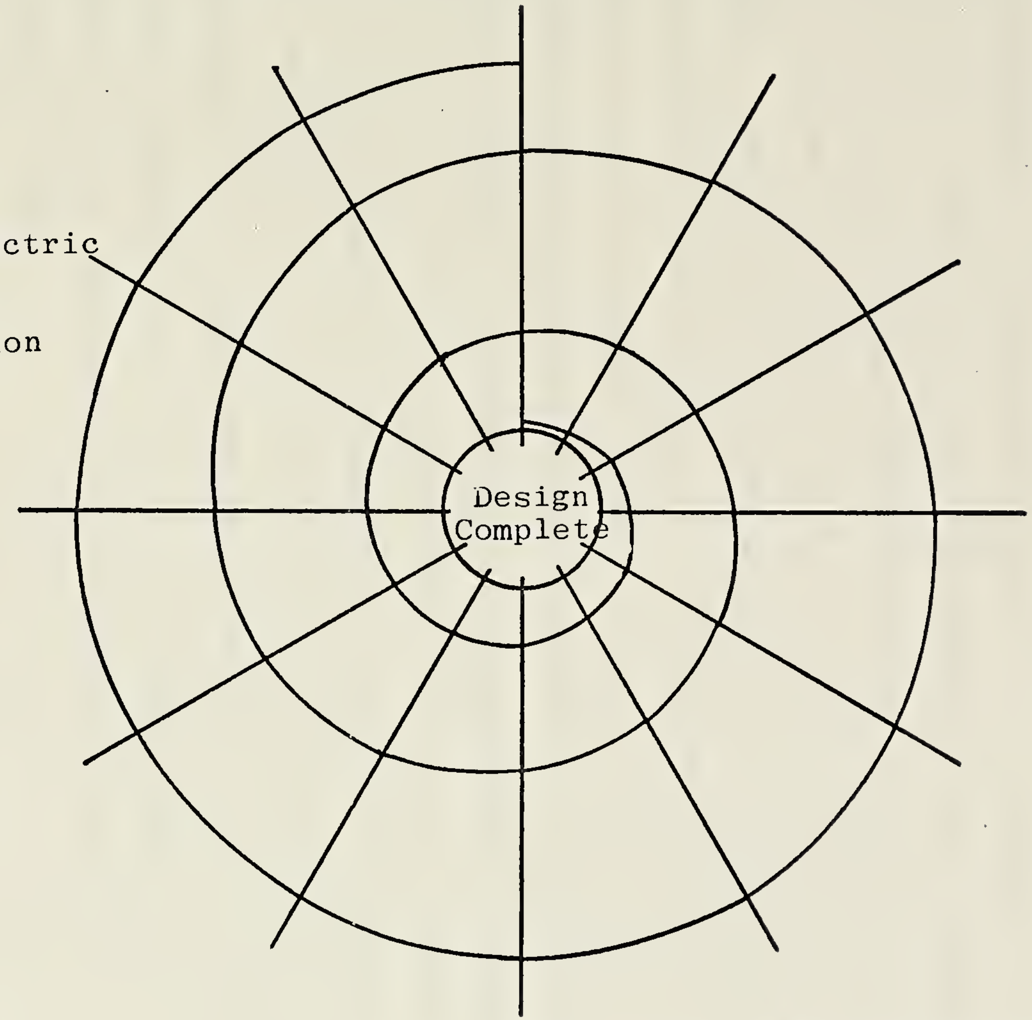
Source: Modification from Ref. 15

Figure 4-1

SHIP DESIGN SPIRAL

Design Elements

Sizing and Powering
Propulsion Machinery
Curves of Form
Equipment List
Auxiliary Machinery Electric
Plant
Structure Displacement
Resistance and Propulsion
Endurance Seakeeping
Weights and Centers
Trim Intact Stability
Damaged Stability
Design Requirement



First Turn = Feasibility Design
Middle Turn = Preliminary Design
Last Turn = Contract Design

Figure 4-2 Source: Modification from Ref. 15.

of cost estimating are used, parametric cost estimating and engineering cost estimating. Parametric cost estimates, the "top down approach," utilize gross, parametric cost-estimating relationships to determine the cost of the ship and its components. This type of cost estimate is most often used in the conceptual design process when the design of the ship is in its early stages and firm ship characteristics are unknown. Engineering cost estimates utilize the "bottoms up" approach to cost estimating. This approach allows the engineer and cost analyst to start at the lowest level possible and estimate the cost of a system or ship from the smallest component, to equipment, to subsystems, to system and finally to the ship level itself. In actual practice, as the design definition becomes more firm the parametric cost estimate and the engineering cost estimate should meet somewhere in the middle and their estimates should serve to check each other to provide the project manager as accurate a cost estimate as is possible within some confidence level.

Cost estimating of naval ships encounters problems which are peculiar to the Navy, few of which are encountered by commercial shipbuilders. First, Navy ships are significantly more complex. For example, the electronics and ordnance systems are extremely complicated and the integration of all of the ship systems to make the vessel an effective fighting unit is very difficult. Even though new design commercial ships may have a large degree of automation,

nowhere else in the shipbuilding industry is there a necessity for the integration of systems to the extent that exists in Navy ships. Second, Navy ships have extremely high technical risk due to the requirement to incorporate a high level of technological advancement to ensure they are and will remain current as a combatant when they become operational in the fleet. Third, the projects in the ship construction appropriation are of extremely long duration. The length of time required to construct a ship considerably hampers the cost estimating problem, since the ship budget must include development costs, the basic construction price, change order costs, escalation of labor and material costs, and any other expected cost growth. Predictions of these costs into the future becomes a very difficult venture.

Some of the other cost estimation problems can be more easily solved. Specific design input data needs to be expanded, more detailed information than in the basic seven weight groups (Appendix A) must be supplied to improve the estimation process. Since commercial shipyards, like most business enterprises, use different accounting systems, construction costs are often difficult to decipher. Some method must be devised to allow the government to determine what the actual construction costs will be at a potential commercial shipbuilder's shipyard.

2. Life Cycle Cost

The Department of Defense Life Cycle Costing Guide states, "The Life Cycle Cost of a ship is the total cost of

acquisition and ownership over its useful life. It includes the cost to the government of development, production, operation and disposal. The two basic considerations that influence life cycle cost decisions are cost and effectiveness. When making a cost-effectiveness analysis, the decision maker must consider every relevant expenditure that will have to be made in the future for each alternative, as well as every future benefit or achieved objective that will result from each alternative."[1]

There obviously is no requirement for a trade-off if all of the alternatives are equally effective. If the alternatives are of equal cost, the most effective alternative is chosen. A trade-off decision is required, however, when the most effective alternative is not the least costly. The decision must be made considering whether the additional effectiveness is worth the higher cost. As the number of trade-off parameters for each alternative increases, the determination of preferences between alternatives, each of which gives one combination of the parameters, escalates very rapidly in difficulty.

The greatest trade-off flexibility is achieved when overall system operational requirements are specified. For example, if the requirement for reliability or maintainability was fixed, mission oriented values for the complete ship would be preferable to values for the subsystems. The value for the entire ship would make it easier to respond to new information and would allow the revision of subsystem

planning values without requiring a change in the fixed requirement. Similarly, if requirements could be fixed in terms of total life cycle cost and effectiveness, instead of in narrower terms, then the flexibility of continuing trade-offs would be substantially improved.(1)

Life Cycle Cost analysis requires the use of models that are different from most cost models used today in that they should incorporate operating and suport costs rather than just acquisition costs. These models are based on cost estimating relationships. An example of a very simple cost estimating relationship might be the cost of an item which is directly related to its weight; that is

$$C = DW$$

where C = cost of item in dollars

D = a cost-weight factor in dollars/lb of weight

W = weight in lbs

It should be remembered that use of the CER depends upon judgment that the historical data processed into a CER reflects sufficient commonality with the proposed new item being costed to give a reasonable estimate of the latter.

As information about the ship design and its use increases during development, and as decisions committing larger amounts of money are required, more detailed costing becomes feasible. Total ship cost may now be broken into finer details such as hardware, personnel, training, and facilities. The elements are related through cost equations

which reflect in detail the way the elements interact when the ship is developed, produced, operated, and supported.

Other important cost factors include the choice among alternatives in the following areas: contractual requirements, both qualitative and quantitative; hardware and software designs; proposed product improvement effort; preventive maintenance programs; corrective maintenance concepts such as throwaway versus repair of failed items (and the associated choice of level of repair); personnel; support systems; operating procedures, and other items that can influence the life cycle cost and/or effectiveness of the system.

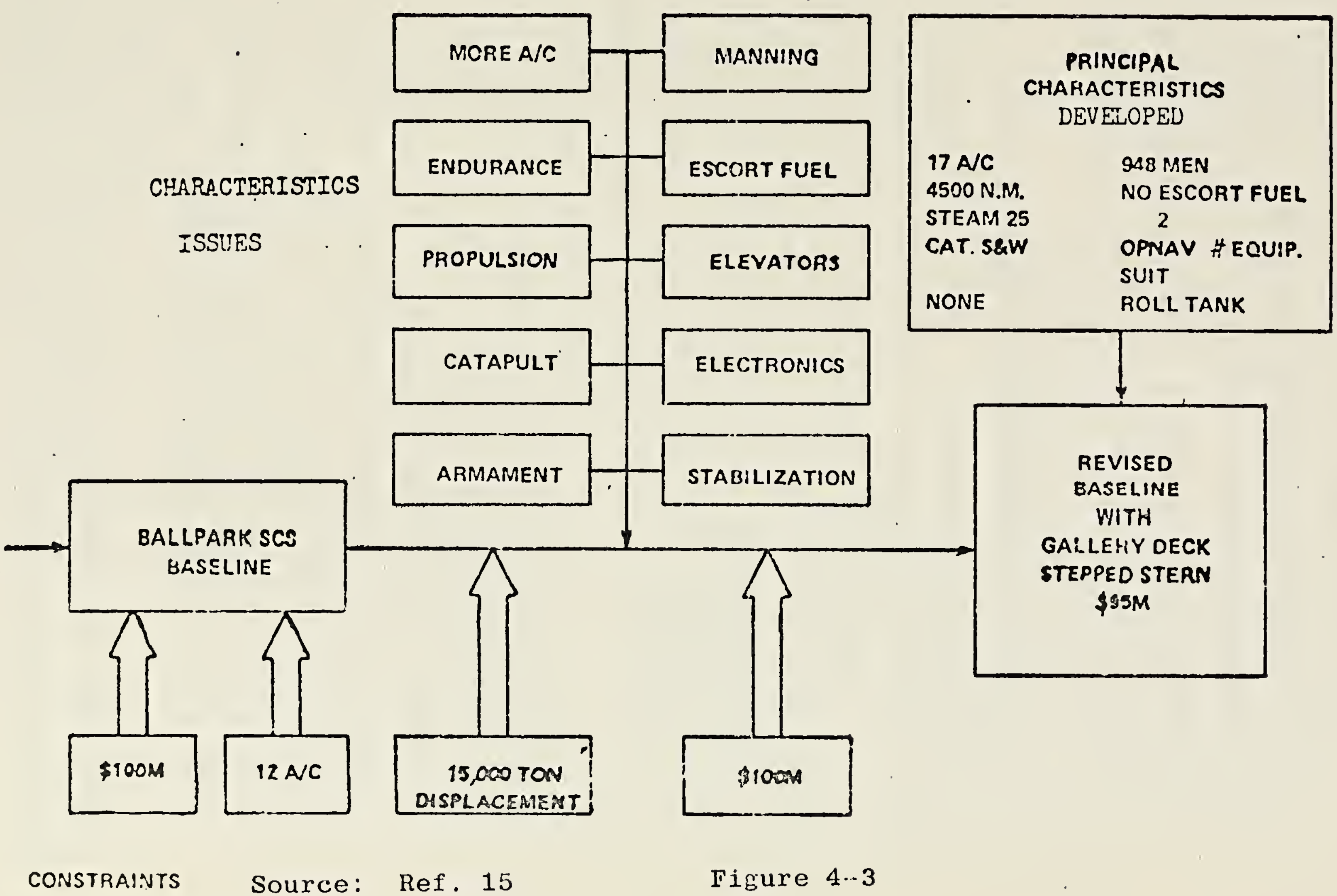
3. Examples of Cost and Performance Trade-Offs[15]

Three examples of cost-performance trade-offs are shown below. The order of the three trade-offs is from those which would have a major impact on the design concept to trade-offs principally affecting selection of a particular subsystem, with system configuration trade-offs in between.

a. Sea Control Ship (SCS)

This example is taken from the experience of NAVSEC personnel with the Sea Control Ship (SCS) during its feasibility design phase. The issues at hand were the selection of major ship characteristics by means of cost-capability trade-offs. The ballpark SCS was constrained to $100 million and 12 aircraft. A ship feasibility baseline existed at the start of this design phase. Characteristics at issue are shown in Figure 4-3. The Program Sponsor in

DEVELOPMENT OF REVISED SCS BASELINE



Source: Ref. 15

Figure 4-3

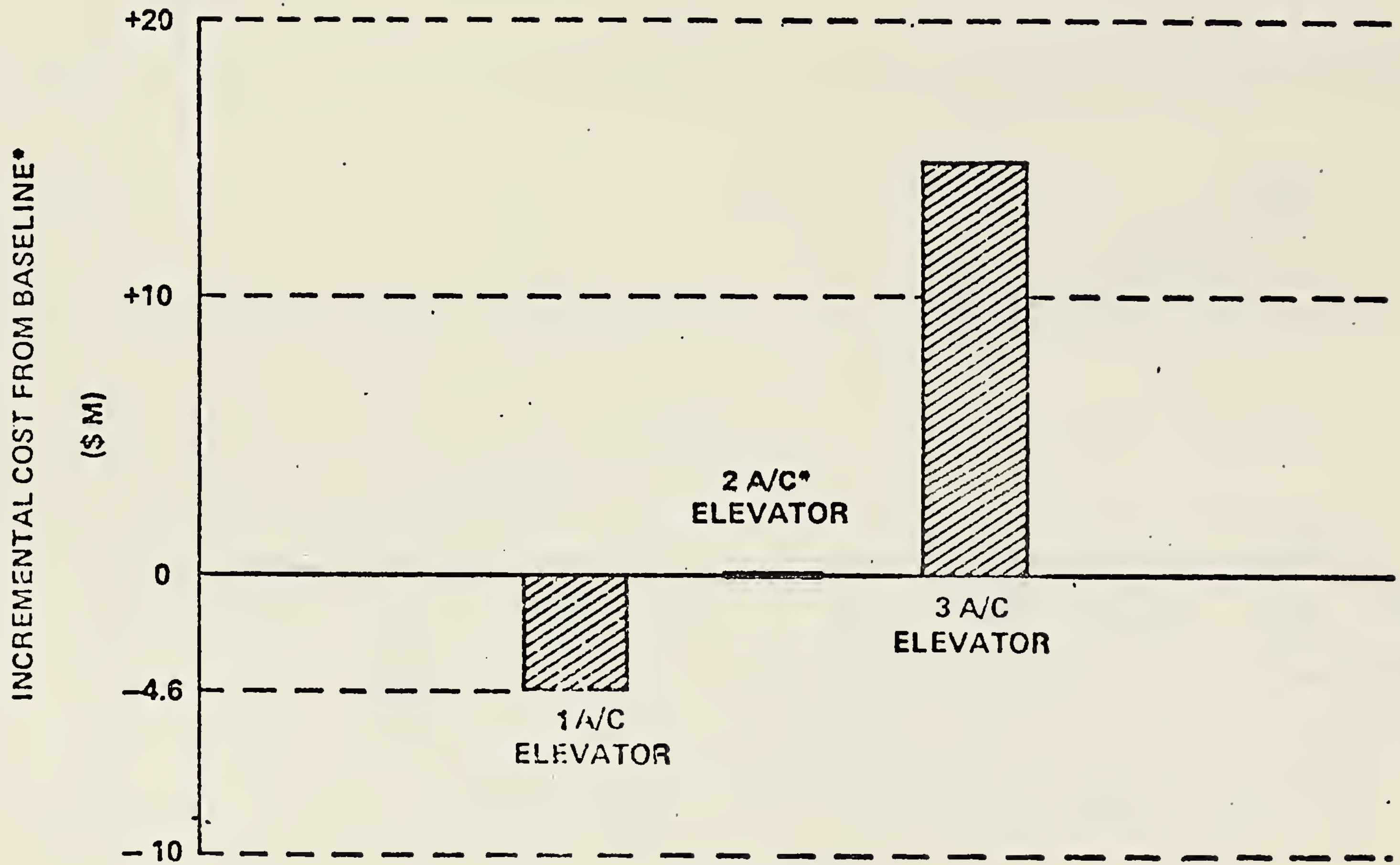
OPNAV wanted more aircraft and less manning. No position existed for carrying fuel for refueling surface escorts, and an armament suit had not been decided upon. During the feasibility design a tentative maximum displacement design goal of 15,000 tons was established. Trade-off studies were made leading to decisions on the principal characteristics shown in Figure 4-3. Two of these trade-offs are discussed below.

(1). First consider how the number of elevators affects ship acquisition costs. The baseline ship had two elevators. Removal of an elevator lessens high weight, the ship shrinks to keep the same stability and strength, propulsion power decreases and less auxiliary and electrical power are required. The three elevator scheme, by virtue of arrangement space, has a larger cost differential than the one elevator scheme. Incremental costs of aircraft elevators are shown in Figure 4-4.

(2). Second, consider the number of aircraft and percent hangared, and their effect on ship acquisition cost as shown in Figure 4-5. Operational hangaring in terms of aircraft capacity, with five being the baseline for the ship, is to be traded-off. The number of aircraft carried affects simultaneous air operations and thus the flight deck size. This is the principal determinant of ship size in this type of ship.

By this process, in each characteristics issue area, the incremental costs of ship characteristics were considered

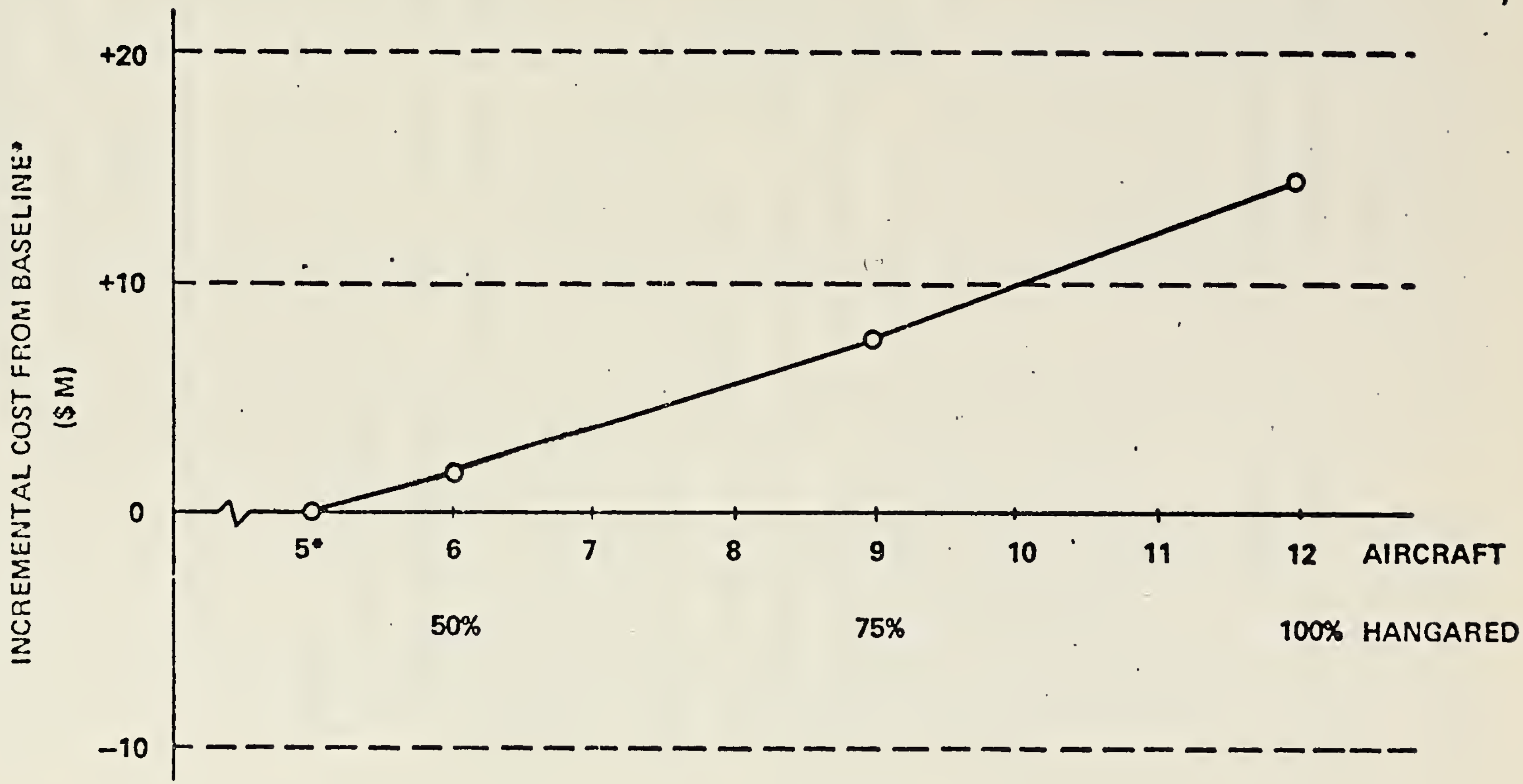
NUMBER OR ELEVATORS VERSUS SHIP PRICE



Source: Ref. 15

Figure 4-4

NUMBER OR AIRCRAFT & PERCENT HANGARED VERSUS SHIP PRICE



Source: Ref. 15

Figure 4-5

with the inherent operational capability of the characteristics to decide on the revised baseline ship. A better statement of design requirements was developed and the design constraints of cost and displacement were decided.

b. Electric Power Generation.

Consider the subsystem design concept for the electric power generating plant of a destroyer type ship. In this example, the issue is how to meet the power requirements of the ship. Costs include the equipments and their impact on ship design. The design envelope at the time of this trade-off was a ship which was well over cost ceiling.

Four electric generation cases or alternatives are shown in Figure 4-6. The configurations signify the number of diesel generator sets times the nominal capacity of each generator. Baseline case one, for example, has four generator sets at 500 KW each for 2000 KW installed.

Certain design standards have been followed as regards the ship's electric plant. As Navy ships have generally had lives of up to 30 years and have had major changes in their weapons and electronics suits at roughly 10 year intervals, a 30 percent growth margin is usually installed relative to the required load to allow for increased electrical demand over the life of the ship. In battle conditions, the electrical plant must carry the full load with one generator shut down. The growth margin shown in Figure 4-6 is with one generator shut down and varies about the 30 percent standard. For reference, the

ELECTRIC GENERATION ALTERNATIVES

CASE	CONFIGURATION	GROWTH MARGIN	SHIPBUILDING COST
1	4X500 KW	14.50%	$2.75M
2	5X500 KW	52.67%	$3.40M
3	3X750 KW	14.50%	$2.43M
4	4X750 KW	71.76%	$3.40M

Source: Ref. 15

Figure 4-6

design loads at the time of the trade-off were 1310 KW in battle and 1150 KW in cruise condition. It can be seen from the figure that cases two and four will satisfy cruise power with two generator sets off the line. The listed shipbuilding costs were obtained from a CER developed for a set of destroyer type ships where the parameter is simply installed KW.

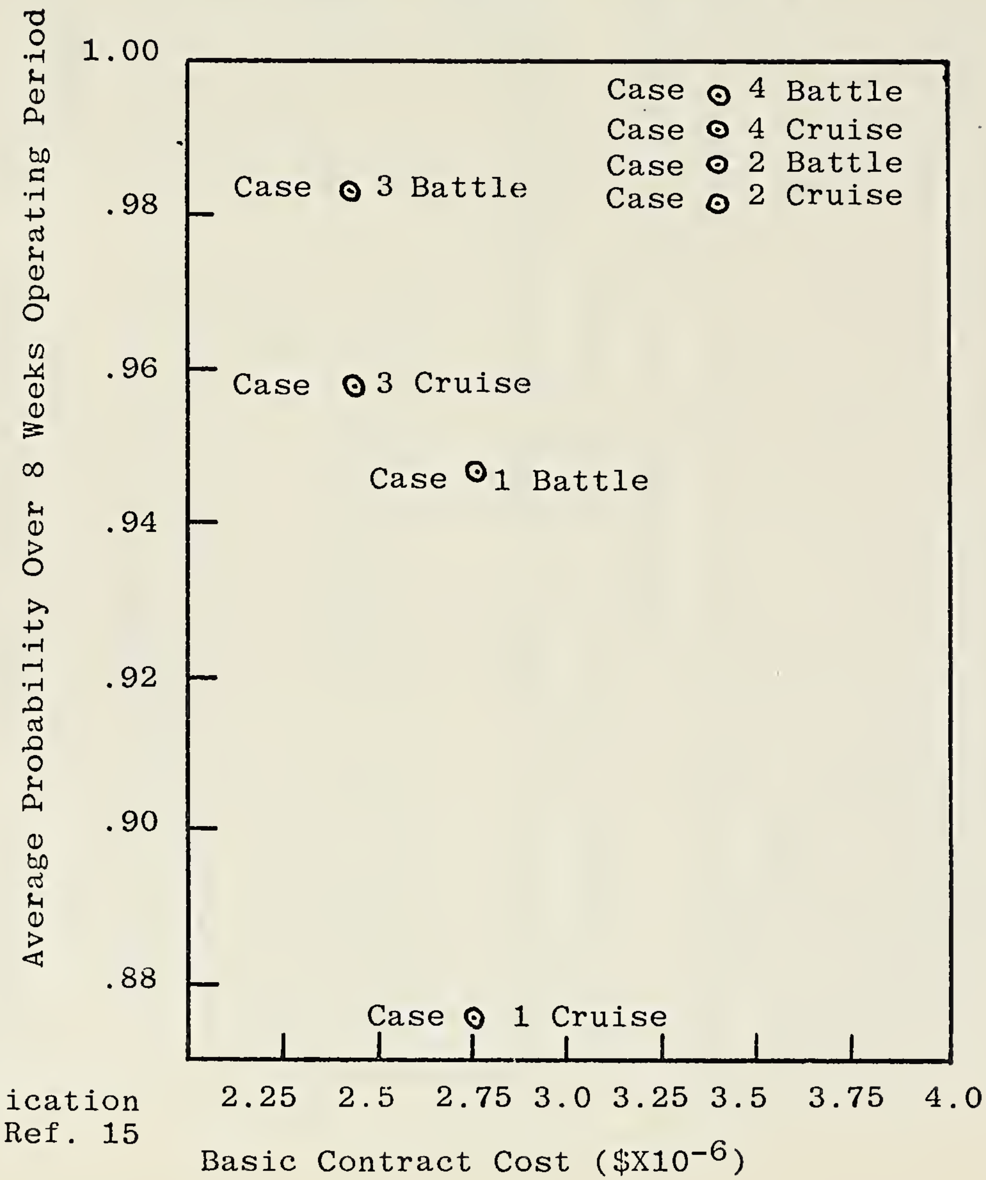
Reliability analyses were performed for all four cases; the probability of providing battle and cruise power was calculated for an eight week period of deployment. This is the measure of performance effectiveness used for all cases. Assume that a minimum probability of .87 is specified under any condition. The issue of cost-effectiveness is then displayed in Figure 4-7 for selection of the configuration alternatives. Note in Figure 4-7 that case one gives a low probability of meeting the eight weeks power requirements. Conversely, cases two and four have high performance, but at a cost penalty. Case three is the superior choice in terms of reasonable cost for an acceptable level of performance.

c. Selection of Subsystem Alternatives

In considering the choice among subsystem alternatives, costs can be grouped into the following categories; equipment, installation, operating and support costs, and their impact on the total ship design. Equipment costs are straightforward, installation costs, and operations and support costs are developed by the use of cost estimating relationships.

Figure 4-7

CONFIGURATION TRADE-OFF RESULTS



Source: Modification from Ref. 15

The general approach develops a set of cost factors to be applied by subsystem designers in their consideration of the ship cost consequences of selecting a design concept. The factors are relative to a design baseline, and they are clearly applicable at the conceptual phase of the ship design before too many characteristics are fixed, as well as in later phases. The cost factors illustrated in Figure 4-8 are the results of assumed independent changes in manning, electric power requirements, deck space, and weight on the ship design. These marginal costs are applied to the appropriate change accompanying subsystem design alternatives. The following comments are appropriate:

(1). The manning factor includes habitability, food, stores and air conditioning in addition to the cost of the man.

(2). The electric power factor is constrained by the fact that the typical availability of equipment is in discrete steps of 250 KW.

(3). The space factor is a consideration of the cost of area or the effect of length and beam on the ship design.

(4). The weight factor depends on the parameter D (distance from ship keel). If D = 0 (weight at the keel), ship cost decreases because stability driven beam is reduced and thus a smaller ship will result.

'MARGINAL' SHIPBUILDING COSTS

PARAMETER	COST FACTOR
MANNING	\$23,300/MAN
ELECTRIC POWER	\$722/KW
SPACE	\$336/FT^2
WEIGHT	\$(54.3D-200)/TON

Source: Ref. 15

Figure 4-8

D. SCHEDULE AS A TRADE-OFF PARAMETER

Although schedule is of lesser importance in the initial phases of ship design, it is schedule that starts the acquisition and schedule, along with cost, which drives the acquisition in its later phases. All systems and equipments are programmed to achieve some initial operating capability (IOC) date. To this end, the consideration of schedule is an important parameter to the project manager. Schedule is concerned with the timing of events in the acquisition process. New subsystem or equipment developments as well as the ship development must proceed along a planned time schedule to insure that a viable weapons system is operational in the fleet at the proper time.

The project manager's concern for time and schedule cause him to assess each trade-off for its impact on schedule as well as performance and cost. After contract award, timing of events becomes critical not only because of timeliness considerations but because now delays in scheduled events directly translate to cost. In the later stages of ship construction, the considerations of cost and schedule begin to override considerations of performance .

The concern for schedule by the project manager requires him to use some type of information system which will show him where he is on his time line and how his ship acquisition plans are functioning. Schedule tracking systems available include the much publicized PERT technique, first used in

the development of the Fleet Ballistic Missile Submarine, program milestone charts, which indicate the planned date of accomplishment of key events, technical performance milestone requirements, which can be used to measure a contractor's progress on key performance parameters of the project, and PROMAP,[16] another computer-based network schedule tracking system similar to PERT, developed by the School of Engineering and Applied Science at UCLA from their TRANSIM System Simulator Model.[17]

Trade-off alternatives in the development and construction of ships must consider the impact on schedule. The control tools indicated above can assist the project manager in assessing and measuring trade-off impact on schedule.

V. CONCLUSIONS AND RECOMMENDATIONS

In the preceeding chapters, the sequence of and responsibilities for the decision-making process in the planning and acquisition phases of the ship acquisition life cycle have been discussed. Some of the techniques and tools used by Project Managers to assist them in making their cost, schedule and performance trade-offs have been described.

This chapter presents some of the conclusions resulting from a review of past actions. Recommendations are made in several of the areas discussed.

A. AGE OF THE FLEET ANALYSIS

Age of the Fleet Analysis predicts the obsolescence of current Fleet units. Personnel interviewed at NAVSEC indicated that insufficient time was available during the conceptual phase to explore and optimize the conceptual design solution and to fully investigate the various trade-offs between cost and performance. The conceptual process should begin early enough to allow sufficient time to investigate all viable alternatives, using Age of the Fleet Analysis, taking into account the estimated time required for development and construction of follow-on ships. OPNAV must make the determination sufficiently early that a class of follow-on ships will be required to meet the existing need to allow optimization of the conceptual design. The

dollars expended at this point in the life cycle for such trade-offs are minor compared to the costs incurred during development and construction. If the conceptual design process is begun early during the conceptual phase, changes to the program, or even program termination, have little cost impact as compared to the cost of changes required during development or construction.

B. THREAT AND MISSION ANALYSIS AND DEVELOPMENT OF MISSION PROFILES

Threat and mission analysis and the development of mission profiles is the responsibility of OPNAV. Personnel within the technical commands indicated that, while OPNAV was identifying the threat and was presenting some ideas of what it thought would meet the threat, the development of mission profiles was being left up to the technical commands, if done at all. As the representative of the ultimate user of the product, OPNAV determines the operational use of the ship and should, therefore, develop complete mission profiles. By passing this responsibility to the producer, OPNAV may be allowing the ship designer to develop mission profiles which support his design instead of having the ship design support the mission profiles.

C. OPNAV PARAMETER CONSTRAINTS

The broader the requirements criteria are, the more flexibility is allowed the designer to investigate the effects of possible trade-offs within the design solution to meet

operational requirements. In the development of the old "single sheet characteristics" (now the Top Level Requirements), OPNAV must ensure that it does not become too specific in its requirements, particularly at subsystem and equipment levels. To achieve maximum trade-off flexibility, OPNAV should only specify the operational parameters and allow the design engineer to develop the ship design parameters that will satisfy the operational requirements. For example, when OPNAV determines that the ship must be able to achieve a certain speed, with gas turbine propulsion and one screw, it has effectively pre-designed the ship for the design engineer. He will have the ship sized and powered before he gets involved in the design process.

D. TOP LEVEL REQUIREMENTS/TOP LEVEL SPECIFICATIONS (TLR/TLS)

The advent of TLR/TLS would appear to provide the user and the producer a better opportunity to conduct a dialogue and to weigh the possible alternatives to satisfy a need. It also should provide a better flow of information between the user and the producer, thus allowing the inputs of each to be fully analyzed and lead to a more orderly acquisition process. The danger in this new procedure is that it could just become another "paper work exercise" and, therefore, not accomplish its intended purpose of exchanging ideas and investigating alternatives before the ship design is finalized. TLR/TLS should document the orderly flow of decisions, their causes, and how the final decisions in the acquisition process were reached.

E. CURRENT OPERATOR INPUT

1. Conceptual Design

The use of an Ad Hoc Panel to investigate the desirable features of ships and submarines and their value in a real world operational environment has very potential benefits. This would bring the influence and experience of the current operator into the acquisition process to assist headquarters personnel in developing operational requirements as well as ship characteristics, since the headquarters personnel are removed from the day to day problems of the operating forces. This procedure was used in the design of the SSN-688 class submarine. In this instance, NAVSHIPS assembled a group of recent commanding officers with a vast amount of at-sea experience and essentially asked, "What would you want in a ship which must be able to accomplish these missions?" The Ad Hoc Panel developed a set of proposed characteristics which were then tested at NAVSEC for feasibility and cost impact and aided in the determination of the approved ship characteristics. The Ad Hoc Panel did have the use of conceptual studies which had been prepared prior to their involvement, but in addition, the at-sea experience of these individuals assisting the ship design personnel proved to be a successful venture. The use of this type of Ad Hoc Panel would appear to be of significant value to all ship class acquisitions.

2. Development and Construction

Many of the decisions that are made within the project office, as a ship is undergoing development and construction, are made by personnel who have not had recent experience in or are not familiar with the operating forces. A possible lack of knowledge concerning current ship operations could result in a poor decision with respect to some feature of ship and equipment design. If, however, a recent operational line officer is assigned as a member of the project staff, his experience as an operator can be considered when decisions are made. As an example, the assignment of a Marine officer to the LHA project proved to be very valuable to this project in regard to the cargo handling system with which the Marines embarked on this ship will be concerned. It is recommended that appropriate line officers with recent at-sea experience be assigned to project staffs in order to gain the current operator's viewpoint.

F. MULTIPLE-FUNCTION SYSTEMS AND SYSTEM INTEGRATION

In the current environment of diminishing resources available to the Department of Defense, the Navy is forced to investigate to the greatest extent possible, the fullest utilization of its systems and equipments, for example, being able to use waste heat from a gas turbine engine to fire a boiler, or being able to use an equipment's cooling water to also satisfy air conditioning requirements. Multiple-function systems fully utilize the resources

available and maximize their benefits. To achieve such benefits, a total system design approach should be initiated during conceptual design. Allowing the design engineer adequate time to complete the conceptual design process helps to insure that all multiple-function systems and system-integration alternatives are fully investigated and reduces the cost impact of re-design during development or construction in order to take advantage of multiple-function uses.

G. TESTING AND INTEGRATION

Since it is unlikely that there would be a "sail off" between competitive prototype ships, as presently done with airplanes, prototyping must be relegated to the subsystem level. Where feasible, prototyping at the subsystem level should be accomplished during all phases of development. If satisfactory test data can be obtained from experimental models instead of relying on "paper studies," less risk may be involved in proceeding from development to construction. All subsystems can be prototyped at some level. The use of prototypes allows the risk inherent in system integration, a problem which has caused serious difficulties for the Navy in the recent past, to be reduced. It has been the tendency to separately test and evaluate subsystems or components during the construction of ships, however the integration of these systems while being tested has been lacking. It is apparent that more test and evaluation time is required when complex systems must be integrated. The use of land based

test sites is one tool which allows system integration risk to be reduced. This type of test and evaluation is mandatory for systems which are just completing development. The integration of components within one system and each system with other related systems is a vital link in the ship construction phase. If it is impractical for a system or subsystem to be completely prototyped as a hardware model due to cost or time factors, the use of a combination of hardware components supported by simulation, in a land based test site, can prove beneficial.

H. FLEXIBILITY OF HULL FORMS

The Navy should encourage the development of ship platforms which are capable of performing different functions by growth or change, as opposed to developing one ship to solve one need and additional ships to solve other needs. The Surface Effects Ship (SES) hull type, among others, is a development that has the potential for being able to fulfill many types of different missions from a small partol craft to an aircraft carrier. To point its development toward satisfying a specific mission would reduce the potential effectiveness of this hull form and its possibility of being used for different and diverse purposes. The DD-963 class destroyer design encompassed the growth part of this approach. Trade-offs were made to ensure that the hull was capable of withstanding substantial growth during future modernization, if it became desirable to change the primary mission. This

aircraft carrier escort capable anti-submarine warfare (ASW) platform has the potential for conversion to an anti-air warfare (AAW) combatant during modernization at a later stage in its life cycle. In order to take advantage of potential economies, new hull structures should be designed such that they can be converted to satisfy other mission purposes at a future time. Once a specific need is determined for a particular type of hull structure and its use is encompassed in a new program, the basic hull concept should remain in the research and development stage to investigate other possible uses.

I. IN-HOUSE DESIGN CAPABILITY

The advent of using performance specifications in which a contractor is given certain performance thresholds he must meet could degrade the Navy's capability to accomplish in-house detailed ship design and full-scale development. It appears that there will always be a need for an in-house capability to accomplish conceptual design work, but the detailed design requirements are now being performed by commercial contractors. As a consequence of reliance on contractor accomplishment of detailed ship design, Navy shipyards are losing their capability to design and construct new ships. With the recent difficulties experienced in obtaining commercial shipbuilder interest in construction of small quantities of specialized ships such as tenders, it is readily conceivable that the Navy will be required to

design and construct these ships in house using Navy shipyards. It is easier to hire experienced shipyard trade craftsmen, such as welders and pipefitters, than to find experienced detail design engineers who are capable of fully designing ships. It is also necessary to be able to retain the in-house expertise required to evaluate a potential contractor's new ship proposal. In addition, experienced detail design engineers are required to allow the Navy to do a better job of writing performance specifications, so that there can be a clear understanding of what the performance thresholds entail.

J. STATE-OF-THE-ART VERSUS DEVELOPMENTAL RISK

Due to the length of the development and construction phases of a ship and its subsystems, proposals for new improved equipments or subsystems which are being or can be developed must be considered. Weight must be given to the impact on performance, cost, and schedule for the total system should the developmental equipment or subsystem not be available when required. This risk must be weighed against the probable obsolescence of the state-of-the-art subsystem the developmental subsystem would replace. Using a subsystem that cannot adequately meet the need is no better than failing to develop a new subsystem when required. It may be better to reserve space and weight within a new ship and have the developmental subsystem installed at a later date, rather than pay for a subsystem that has marginal

benefit and will require substantial updating or replacement in the near future. The more self-contained a developmental subsystem is, the easier will be the integration problem if it is installed after delivery of the ship. It is conceivable that a subsystem could be developed as a self-sufficient entity with items such as its own power supply and stabilization source. The additional cost could be offset by increased flexibility, less integration design and material costs, and lower requirements for other shipboard equipment which would otherwise be required to provide sources for the new subsystem.

K. UPDATING OF THE NAVSHIPS' COST MODEL

The data input based in the cost model which is presently used by NAVSHIPS is updated annually, upon the completion of new systems, or the input of significant new data from ship construction activities. The cost model data must be updated to allow the prediction of resources required to produce the end product. A specific cost estimate for a ship can be significantly influenced and changed after each updating. The reason for the change results from the cost model unrealistically projecting, in today's economy, certain cost growth categories such as escalation.

The model projects the current limit of $4\frac{1}{4}$ percent allowed by the Department of Defense for escalation. Another problem with the model is that it bases its labor and material costs on the Department of Labor indices. While

this is the best source of information available, it is based on all industrial users of a commodity, not just the shipbuilding industry. In addition, due to geographical location, costs to one shipbuilder for material and labor are not the same as the costs to another shipbuilder. If the Program Manager is using the model to estimate the cost per unit of his class of ships and is working under a produce to cost ceiling, the updating of the model's data base can have a significant impact on his trade-off alternatives.

Even after the ship design is basically frozen, a data update can require the Program Manager to trade-off performance or schedule in order to reduce cost. While there is no question that the model data base should be updated in order to accurately predict budget requirements, the impact of the updating on a specific program's cost ceiling must be evaluated. It is necessary for the cost estimators and program managers to work together to determine the causes of cost growth in a program as a result of updating.

L. SENSITIVITY ANALYSIS OF DISCOUNTING AND ESCALATION

In the ship cost estimation process used today, discounting is seldom included and, as indicated above, escalation is considered at an unrealistically low level. While this may generate from political considerations, if the Navy is to truly attempt to predict the cost of acquiring and operating a ship, the effect of these cost factors must be investigated. At the very least, ship cost estimates should be

tested for sensitivity to various levels of escalation and discount rates. The most realistic manner in which to measure the least expensive alternative, when alternatives entail different levels of cost over different periods of time in the life cycle, is to compare their discounted values after the costs have been escalated. While the time when resources will be required cannot be predicted for all factors, those which can be reasonably predicted should be considered to aid in the selection of the least expensive alternative.

M. ACQUISITION COST VERSUS OWNERSHIP COST

When a program manager is faced with two alternatives, one of which has a smaller acquisition cost, a greater support and operations cost, and a greater total cost, in today's procurement environment the program manager choses the alternative with the lower acquisition cost. This can lead to a dichotomy between the design-to-cost concept, where the program manager is constrained by an acquisition cost ceiling, and the life cycle cost concept where he is supposed to minimize life cycle costs. This problem is created because of the method used to budget and appropriate funds for ship construction. Instead of fully funding the total program, it is funded on a year to year basis. The goal then becomes one of minimizing the year to year resource requirements rather than minimizing total program cost. Since operations and support costs are not included in the Ship Construction Budget, the tendency is not to place sufficient weight on

their impact. When any cost analysis for a system is accomplished, the cost of operations and support must be given equal consideration with the cost of acquisition.

N. PROJECT CONTINUITY

Because of the length of time involved, and as desirable as it might be, no one individual will be assigned as a project manager for ship construction from conception to delivery of the final unit. However, there are several points in the life of a project where a change of project manager can be made with maximum continuity, for example, at the transition from conceptual to the development phase and from the development to the production phase. In the recent past, attempts have been made to relieve project managers at these points and this practice should be continued. As a result of the rotation of the project manager as well as other military members of the project staff. It is essential that the civilian membership of the project staff maintain project continuity. The civilian staff members, by virtue of their long tenure, therefore have knowledge of the rationale for various program changes and trade-offs made either through participation or by first hand awareness. In addition, through participation in the contract evaluation process, they become aware of the agreements and commitments made between the contractor and the government. This becomes of great importance in the later stages of contract completion, when questions arise pertaining to certain contract provisions.

Past experience has shown that turnover of the project personnel on the part of the Navy and contractor has raised questions in regard to contract requirements.

O. FALL BACK POSITIONS

In dealing with any subsystem that involves an area of risk in its development, there should be a fall back state-of-the-art subsystem that can be installed for critical subsystems if the development should be delayed for a significant period or fail altogether. If a fall back equipment is to be considered, there must be adequate provision to insure that it will be available when required. Eventually some point in time is reached when the added cost of continuing the new development while also maintaining the fall back position must be evaluated. At this time, a decision must be made either to drop the fall back positon because the risk in development of the new subsystem has been reduced to an acceptable level, or to drop the developmental subsystem because the cost, schedule, and/or performance risk of its continued development is unacceptable. Another aspect of this type of analysis is to consider when to replace a subsystem of lesser performance capability by one of greater capability that has just completed development.

P. EXTERNAL CONSTRAINTS

The Navy is challenged in the courts each year for a variety of contract claims. The tendency for the contractors to try to receive compensation in the courts has caused some

unfortunate and possibly bad side effects. The threat of litigation to a current shipbuilding program could tend to reduce the willingness of the program manager to make beneficial changes in the program which result from trade-offs made during construction. The availability of the latest service approved subsystem, or the change to a new capability, such as the Close-in Weapons System (CIWS), could make the change very desirable, but an inability to satisfactorily negotiate changes with the contractor could delay the delivery date of the new subsystem to the Fleet.

Q. USE OF POST-SHIPYARD AND TENDER AVAILABILITIES

In the process of shipbuilding, particularly toward the end of construction, there can be many minor contract changes or items which require some correction. Our experience from interviewing personnel on project staffs indicated that very little consideration is given to the cost impact of having these items installed during the post-shipyard availability (PSA) instead of modifying the contract to have the contractor accomplish the change or correction. As an example, in the DD-963 project, the small arms locker was going to be modified as a result of a change to the ship's small arms allowance. There was, however, some doubt as to what mix of small arms would constitute the final allowance. In this case, a small change to the locker specifications would be required, which would easily be within the capability of a tender or supporting base. The question then arises whether the Navy could

conserve funds by having the locker modification accomplished after ship delivery. More analysis needs to be accomplished in the consideration of the cost-effectiveness of having minor changes accomplished by the contractor or during PSA or first tender availability after delivery. In this way, the contractor is faced with competition when requested to submit a bid for the change. He is somewhat curtailed in taking advantage of his sole source situation. Should the contractor not be achieving what he considers a reasonable profit, he could inflate the cost of these late program changes. For example, the aircraft catapult blast deflector for the current nuclear aircraft carrier construction was inadequate to meet the F-14 fighter requirements. After analysing the bids of the contractor and the PSA shipyard, the change was postponed until PSA where it could be accomplished at less cost. The possibility of obtaining bid competition for required changes in ship construction programs should always be investigated. There must be consideration given to the trade-off of reduced cost versus schedule delay.

R. FLEET INTRODUCTION TEAM (FIT) CONCEPT

One of the newest concepts to be used in the shipbuilding process started with the DD-963 program. This FIT concept, which involves a permanent command of experienced officers and enlisted men based at the building yard acts as the nucleus crew for the entire class of ships being constructed.

Consequently, crews ordered to new ships will report as a unit only two weeks prior to the ship's commissioning. The FIT monitors the final ship construction and prepares all shipboard administrative documents and operational doctrines/procedures, other than those prepared by the contractor and the Navy Department. In addition, they train ship's crews upon their arrival and during the post-delivery period prior to commencement of shakedown training. Thus, the crew can devote the majority of their time to learning their ship without having to concern themselves with the myriad of time consuming, pre-commissioning administrative details. This concept has several advantages. It reduces the cost of forming and training the pre-commissioning crew by delaying the time that it must be formed, provides allowance for more initial training time, provides standardization in the ship acceptance process, in that each crew will not be able to tailor the last minute changes to the way they would like to see the ship, and requires less personnel for test and check-out of ship systems since the FIT is fully capable of overseeing the entire process. The FIT concept appears to be applicable to any shipbuilding program where more than a few like ships are being constructed and should continue to be applied.

S. SHIP ACQUISITION LESSONS LEARNED

It appears that there is not a continuing effort by project offices to document lessons learned during the process of each ship acquisition program. While each project is different, many basic problems continue to arise and apply to the majority of the acquisitions. In order that they may benefit from the past, new program managers should and must be aware of previous problem areas. It is recommended that lessons learned be documented by project offices and maintained by NAVSEA. In this manner, new program managers can receive an insight into recurring problem areas. Efforts can then be directed toward reducing those problem areas which continually have significant impact on projects.

APPENDIX A

ELEMENTS OF SHIP ACQUISITION COST

1. Ship Design Inputs

These items give the basic ship cost. (Figure A-1)

a. Government Furnished Equipment (GFE) may or may not be part of groups 2, 3, 5, and 6. Contractor Furnished Equipment (CFE) is included.

b. Most equipment in groups 4 and 7 are GFE or come from other Systems Commands, and thus are not cost inputs here but are later on (i.e., under equipment inputs).

c. The cost elements represent labor and material to construct the ship, to buy the CFE and to install CFE and GFE.

2. Business Inputs

These items reflect engineering and construction services furnished by the shipbuilder in the course of ship construction, and his profit. The shipbuilder's workload and his identity clearly affect these costs. Groups 8 and 9 are not the only shipbuilder individualities but it is convenient to so call them to reflect variations among individual shipbuilders.

3. Program Inputs

This groups a number of other costs funded by the shipbuilding appropriation. The cost elements include:

ELEMENTS OF SHIP ACQUISITION COST

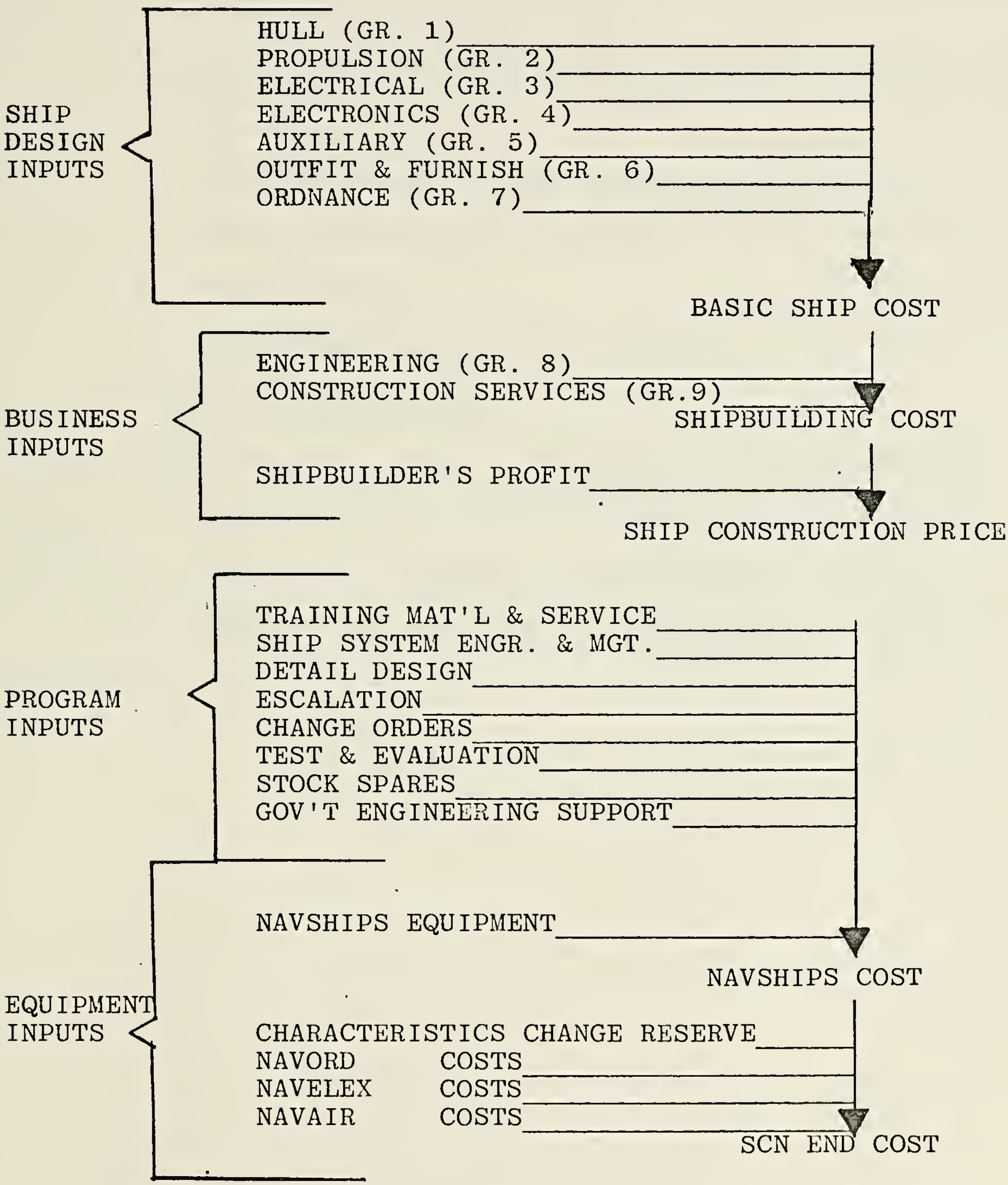


Figure A - 1

a. Training of the first crew, training materials, and schools for the crew.

b. Systems engineering, including logistics support.

c. Detail design for working drawings, principally charged to the lead ship.

d. Escalation in costs during the actual construction period.

e. Changes in ship design during construction.

f. Test and evaluation, nominally of the lead ship.

g. Stock spares.

h. Government engineering support.

4. Equipment Cost Inputs

This cost area comes from the Systems Commands which support the ship project office (hardcore GFE costs) and includes a reserve for changes in ship characteristics during the construction period as a consequence of refinement of the Navy's needs.

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